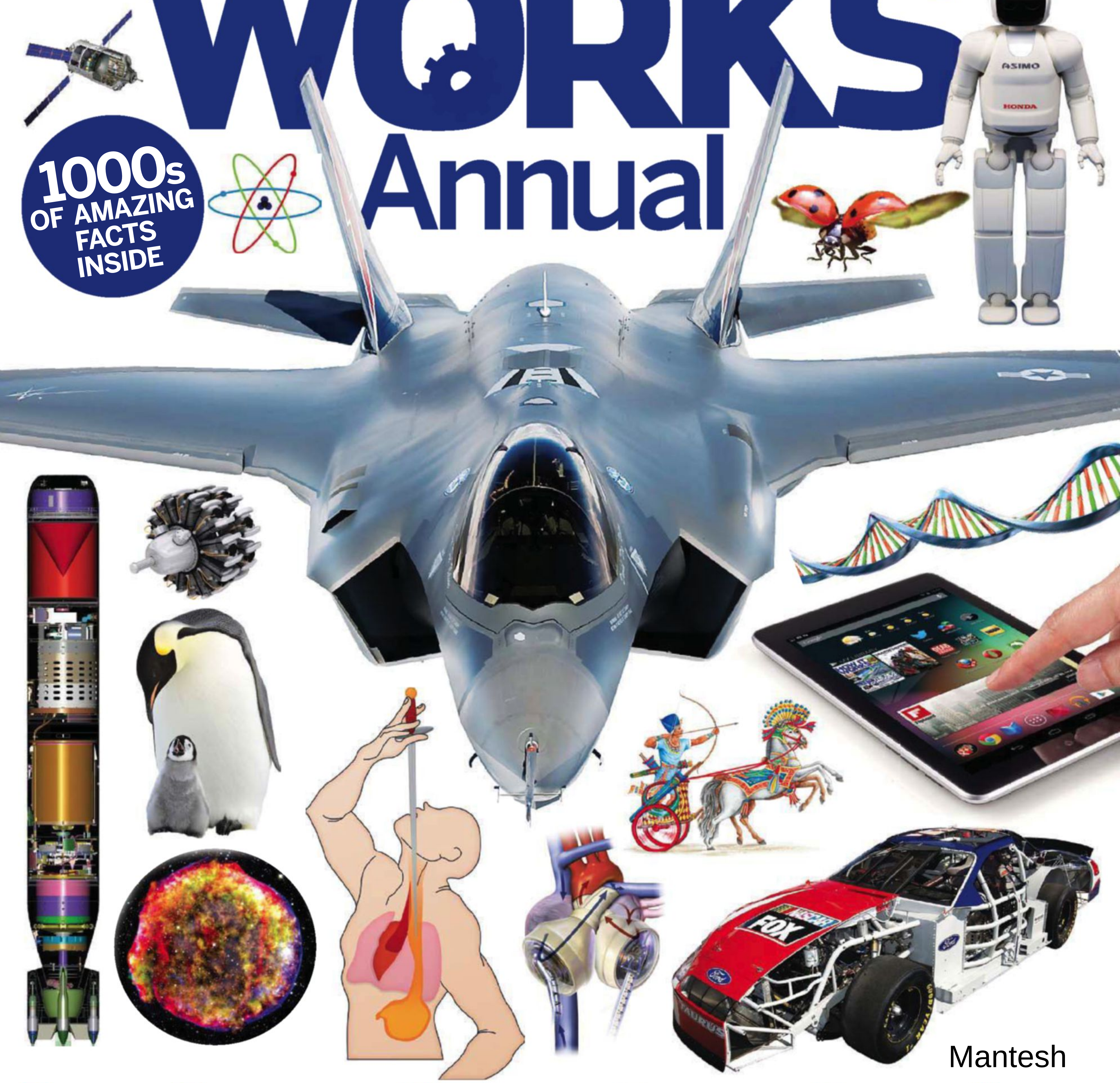
Everything you want to know about the world we live in

HOW IT WORKS Annual

1000s OF AMAZING FACTS INSIDE



SCIENCE | ENVIRONMENT | TECHNOLOGY | TRANSPORT | HISTORY | SPACE

Welcome to HOW IT WORKS Annual

Discover everything you want to know about the world we live in and prepare to be fascinated. With expert help from **How It Works** you can find all the answers to those questions you've been meaning to look up. Absorb yourself in the fascinating facts that you didn't quite pay attention to at school or learn about things you never thought you'd experience in your lifetime, and fuel your imagination with indispensable information now at your fingertips. Detailed cutaway images will reveal the inner workings of everyday items and other intriguing objects, enabling you to see and understand exactly how they work. Breathtaking photos let you marvel at the beauty and spectacle of the world around you, while informative and entertaining articles will prove no question is too big or too small for the **How It Works** team of brains to answer. The annual covers the entire universe across six all-encompassing subject areas: the environment, technology, science, space, transport and history. From voice recognition to mountain formation, lunar eclipses to convertible cars, castles to fake tan, and so much more, you'll find all the answers you'll ever need. So read on and feed your mind with a nutritious dose of **How It Works**.

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HOW IT WORKS Annual

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Head of Publishing
Aaron Asadi

Head of Design
Ross Andrews

Production Editor
Sarah Harrison

Senior Art Editor
Danielle Dixon

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ENVIRONMENT TECHNOLOGY SCIENCE SPACE HISTORY TRANSPORT

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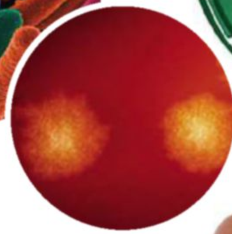

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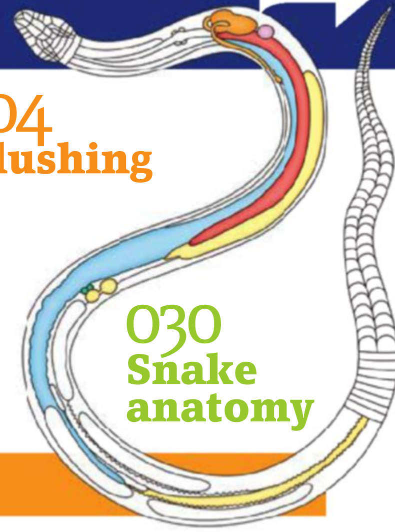

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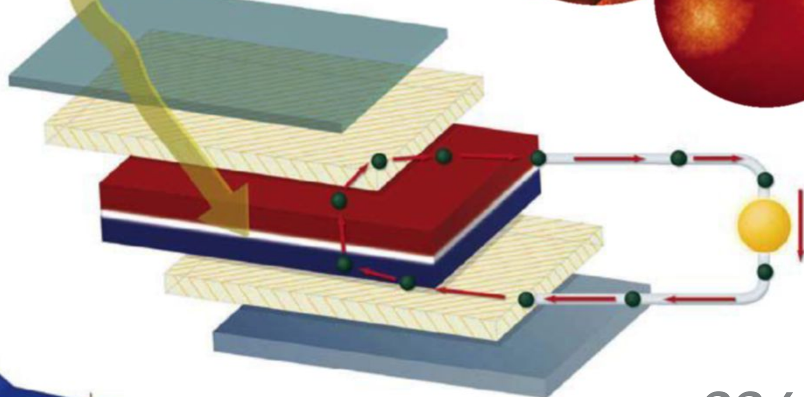

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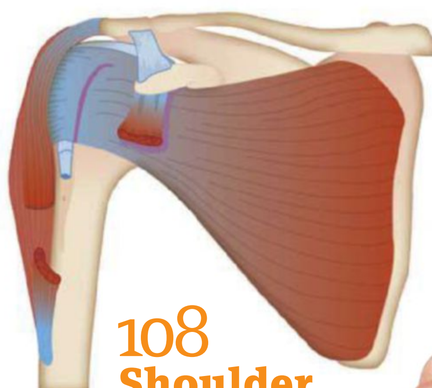

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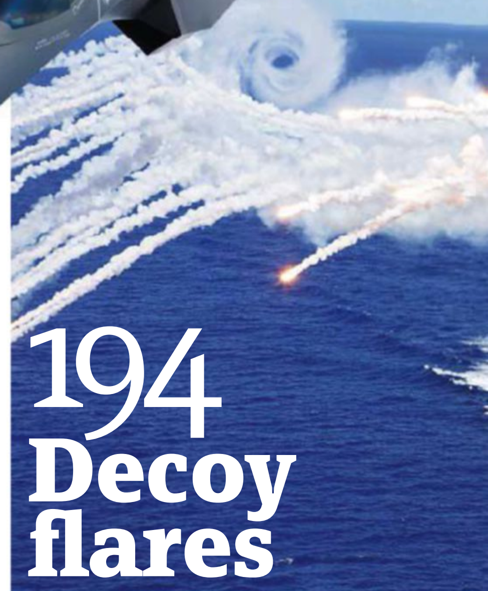

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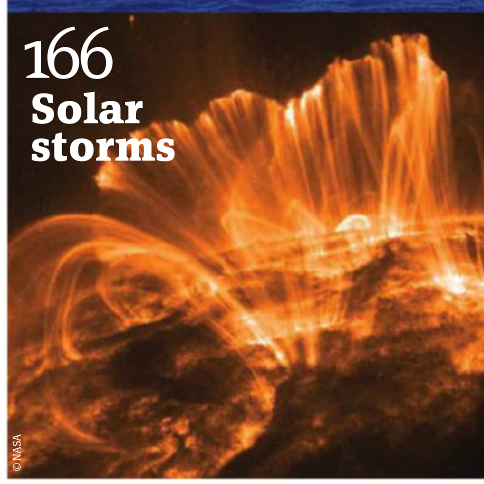

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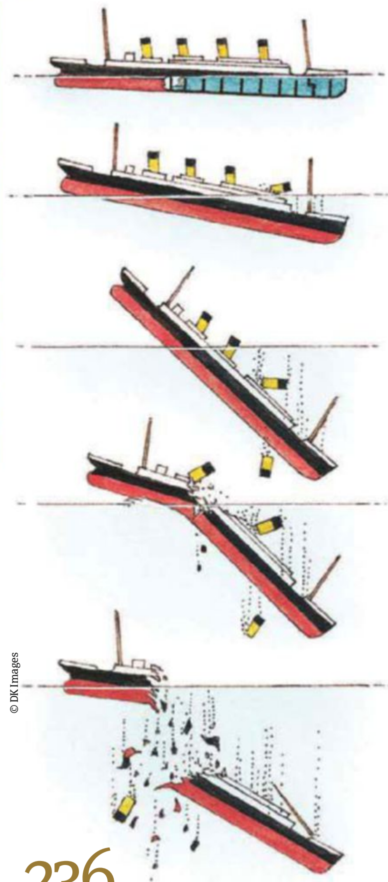

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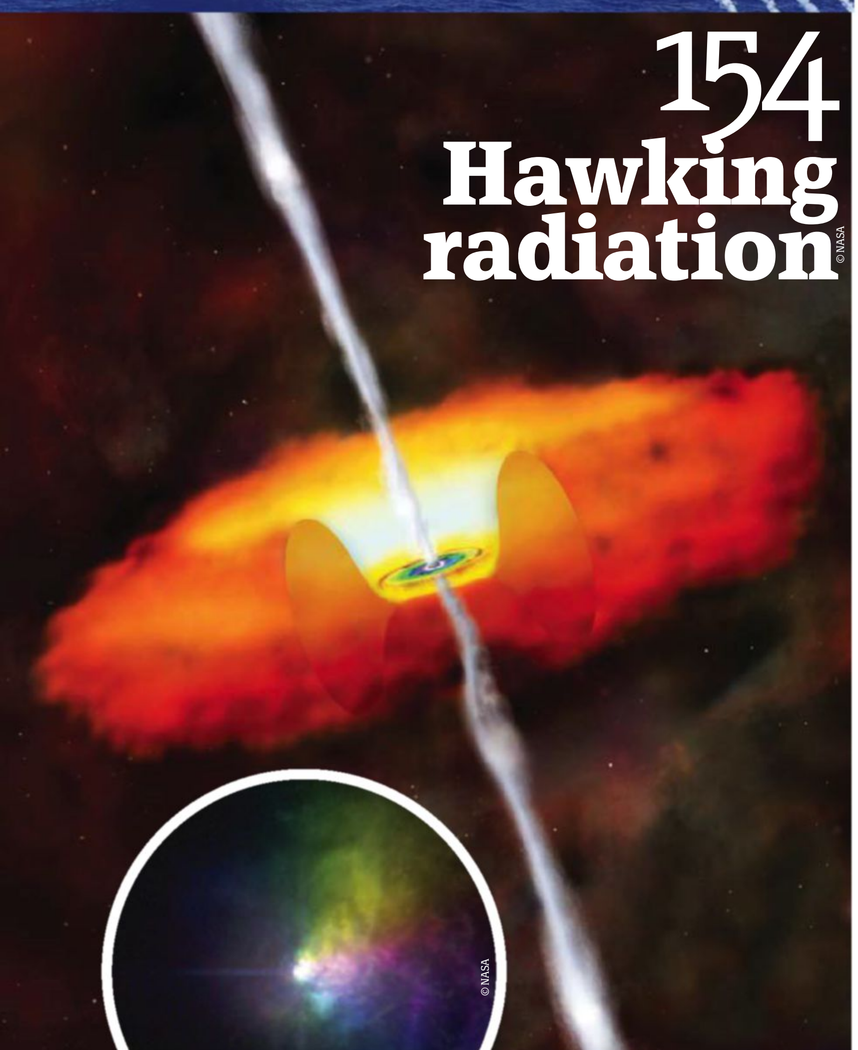

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© NASA

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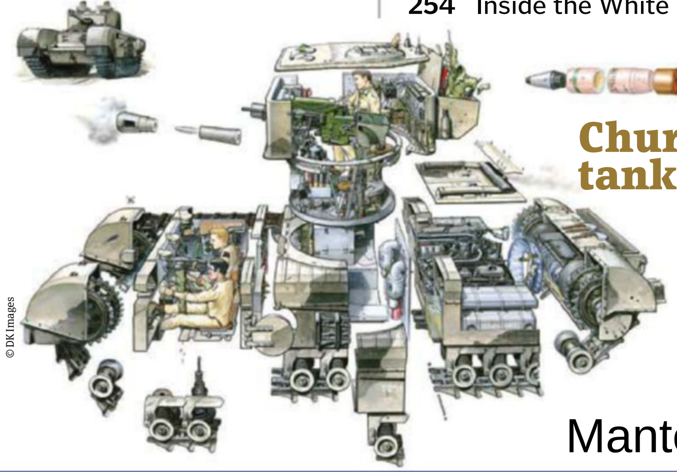

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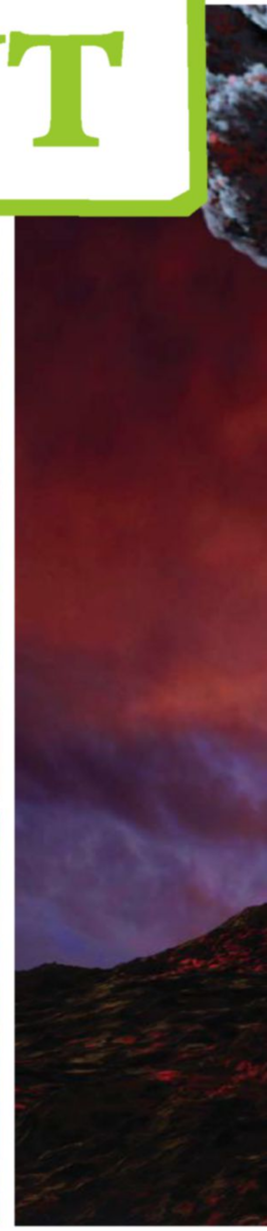

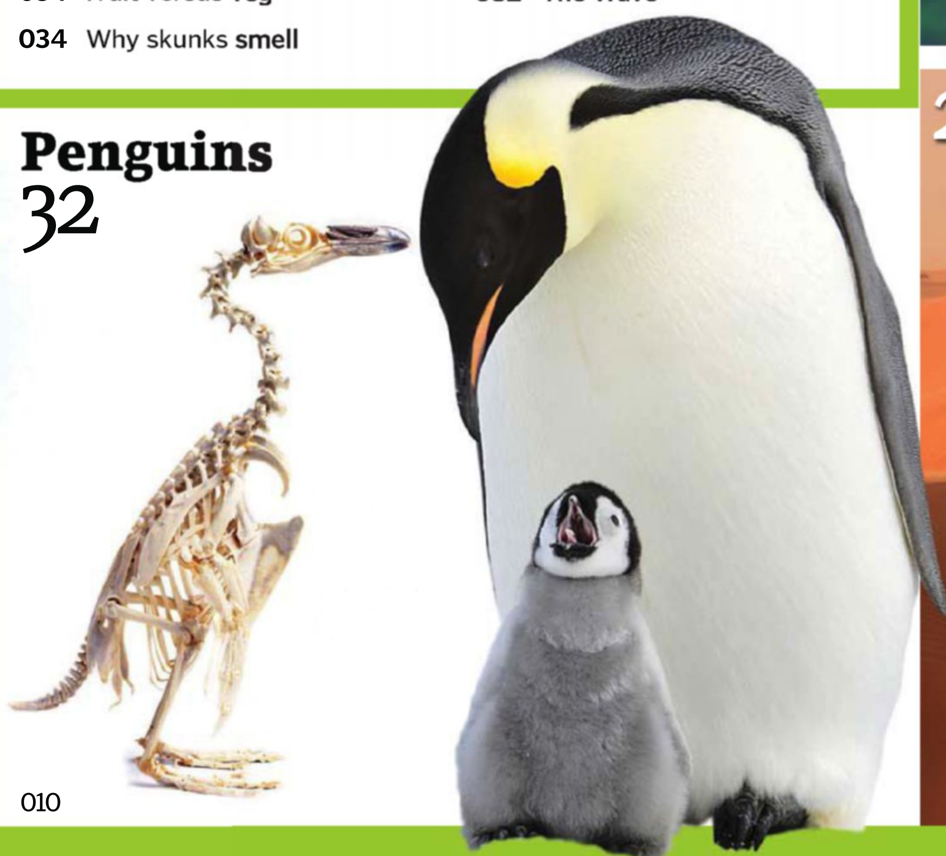

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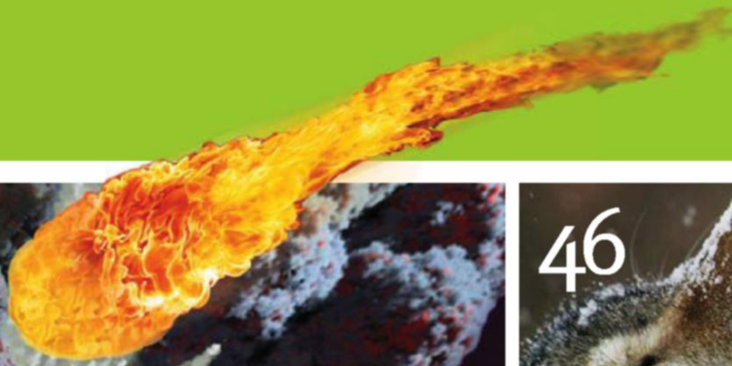

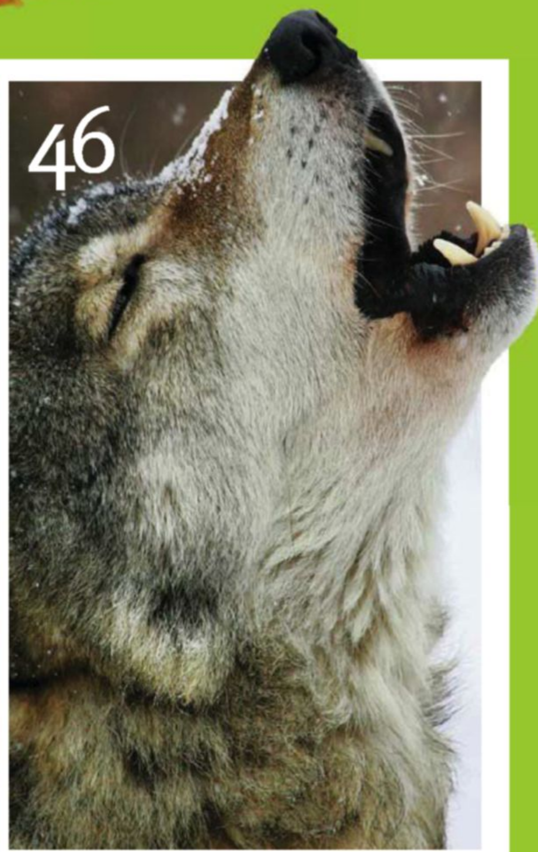

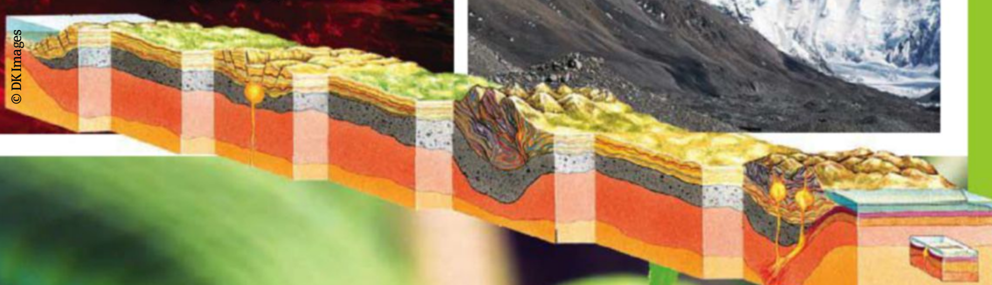

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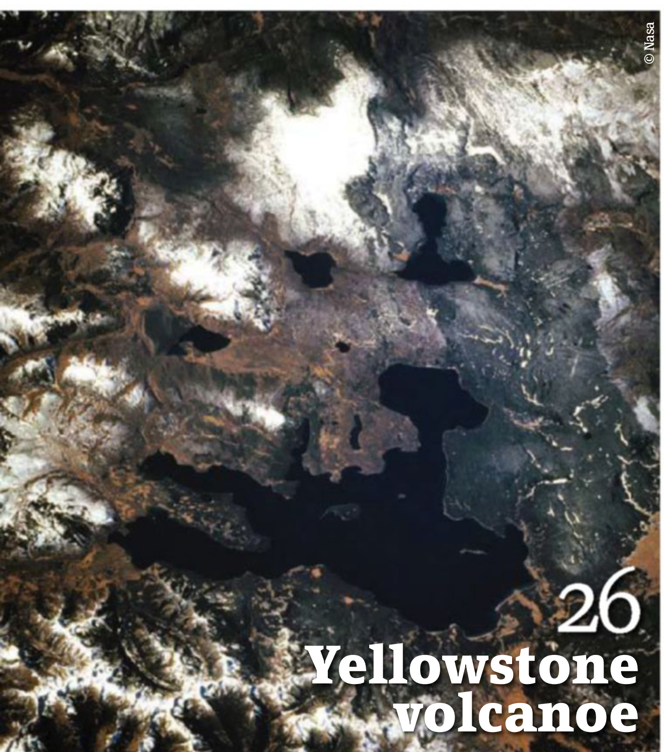


© Nasa

Killer weather

Usually weather is an inconvenience at worst, but having to hunt for your umbrella or turn up the air conditioning is nothing compared to the havoc it can wreak. In an instant, weather can destroy homes, ruin livelihoods, and even take lives…

Monsoons and floods

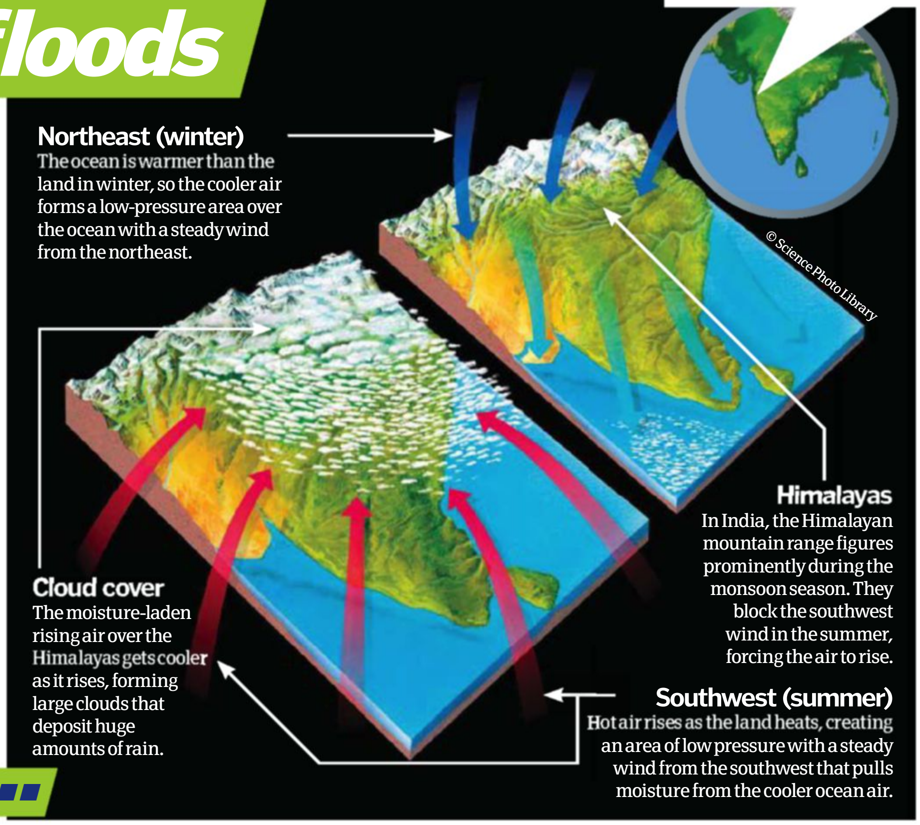
Most likely to find it here…
Mumbai, India

Some of the worst floods are caused by monsoons – massive wind systems that reverse with the seasons and influence weather patterns over large regions of the world. We usually call just the rainy part the monsoon season. How much rain can a monsoon bring? In South Asia, it can mean ten metres (33 feet) of rain in just a few months. It's often welcome – not only for agriculture, but as a relief from sweltering heat.

However, heavier-than-expected rains – especially in low-lying areas that have saturated ground or ground so dry that it can't absorb moisture – can also bring devastation. Flash-flooding happens quickly and can result in fast-moving walls of water up to six metres (20 feet) high, often in areas ill-equipped to handle the overflow. People underestimate the depth of the water and how fast it's moving; they try to escape by crossing the water and sometimes pay with their lives.


© trokilinochchi

Monsoons can bring up to 10m (33ft) of rain in just a few months



Danger ■■■■■ **Destruction** ■■■■■ **Frequency** ■■■■■

Heat waves and droughts

Most likely to find it here…
Baghdad, Iraq

A heat wave is a long period of hotter-than-usual weather – typically exceeding 5°C (9°F) above the average maximum temperature in the area. Prolonged exposure to high heat can cause hyperthermia, or heat stroke, when body temperature spirals out of control. It can be fatal without immediate medical attention. Higher-than-average air conditioning use can cause widespread power outages, making it difficult to keep cool in record temperatures.

Heat waves can also be accompanied by drought, spans of lower-than-average precipitation. Crop failure and wildfires can also contribute to deaths with prolonged periods of heat and drought. Some areas of the world, such as the Horn of Africa, commonly experience both heat waves and droughts. Heat waves are more common in semi-desert and inland desert areas, but they occur throughout the world. Hot air masses formed by systems of high pressure become stationary over an area and, in the absence of clouds, the ground and air both become excessively hot.

Desert areas are more susceptible to heat waves than other areas because they have very low humidity and cloud cover, as well as a lack of geographic features like mountains that might influence wind patterns

© TIM

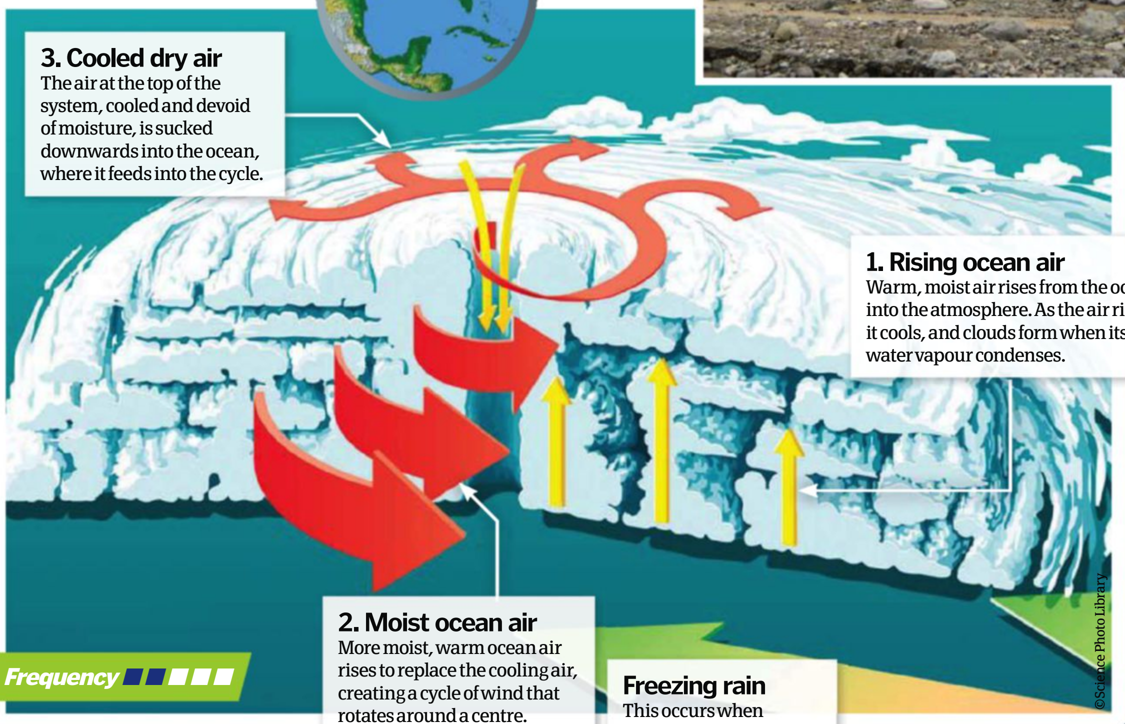
Danger ■■■■■ **Destruction** ■■■■■ **Frequency** ■■■■■

Tropical cyclones


Tropical Storm Agatha swept across Central America in May/June 2010, with Guatemala taking the worst of the damage

The name for a storm system with rotation, high winds and heavy rains depends on not only its intensity, but also the region in which it forms. The mildest form is the tropical depression, which has sustained winds of up to 60km/h (37mph) and rain but no cloud rotation. Next is the tropical storm, which has winds of up to 117km/h (73mph) and a circular shape with rotation.

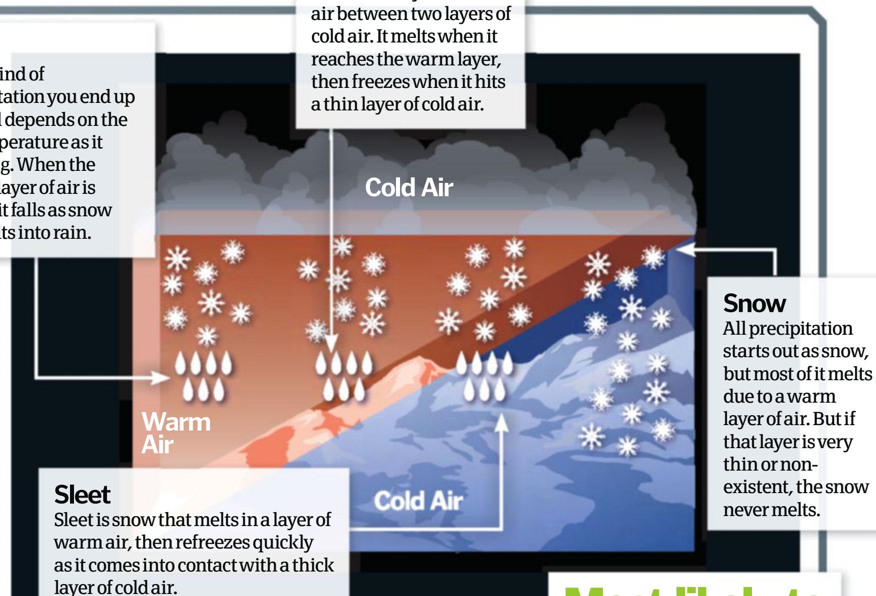
The strongest storm has winds of at least 119km/h (74mph), and a distinctive eye – an area of calm and extreme low pressure. It might be known as a hurricane, a tropical cyclonic storm, a tropical cyclone or a typhoon. They're only called typhoons, for example, when they form in the Northwest Pacific Ocean, while storms that develop in the Northeast Pacific and North Atlantic are hurricanes. It's rare for these storms to be killers, but when they are, they do it big – usually in the forms of flooding, mudslides or diseases after the event.



Danger ■■■■□ Destruction ■■■■□ Frequency ■■□□□

Ice storms


Extreme ice storms can bring down power lines and also burst pipes, leaving people without basic utilities for weeks



Ice storms are the most dangerous of winter storms. They occur when there are two layers of cold air sandwiching a layer of warm air. Rain falls through one cold layer and freezes, falls through the warm layer and melts completely, then hits the second cold layer. Its temperature drops below freezing, but the rain does not actually freeze until it hits the frozen ground. These storms can leave a smooth layer of ice on anything below freezing. Ice on roads is treacherous, and its weight also causes tree branches to fall, blocking roads and bringing down power lines – sometimes the ice alone is enough. Water inside pipes can freeze and burst, causing serious plumbing issues. Death is often caused by carbon monoxide poisoning as people use generators and other heat sources. Ice storms are common in the northeastern United States although they occur in Canada and Europe as well.

Danger ■■□□□ Destruction ■■□□□ Frequency ■■■□□

Head to Head DEADLIEST WEATHER

DEADLY

1. 2008 Cyclone Nargis
This disaster was the worst in Burma's history, causing at least 140,000 deaths and £6.4 billion ($10 billion) worth of damage.

DEADLIER

2. 1970 Bhola Cyclone
Flooding caused by a tropical cyclone that struck parts of modern-day Bangladesh and India killed an estimated 300-500,000.

DEADLIEST

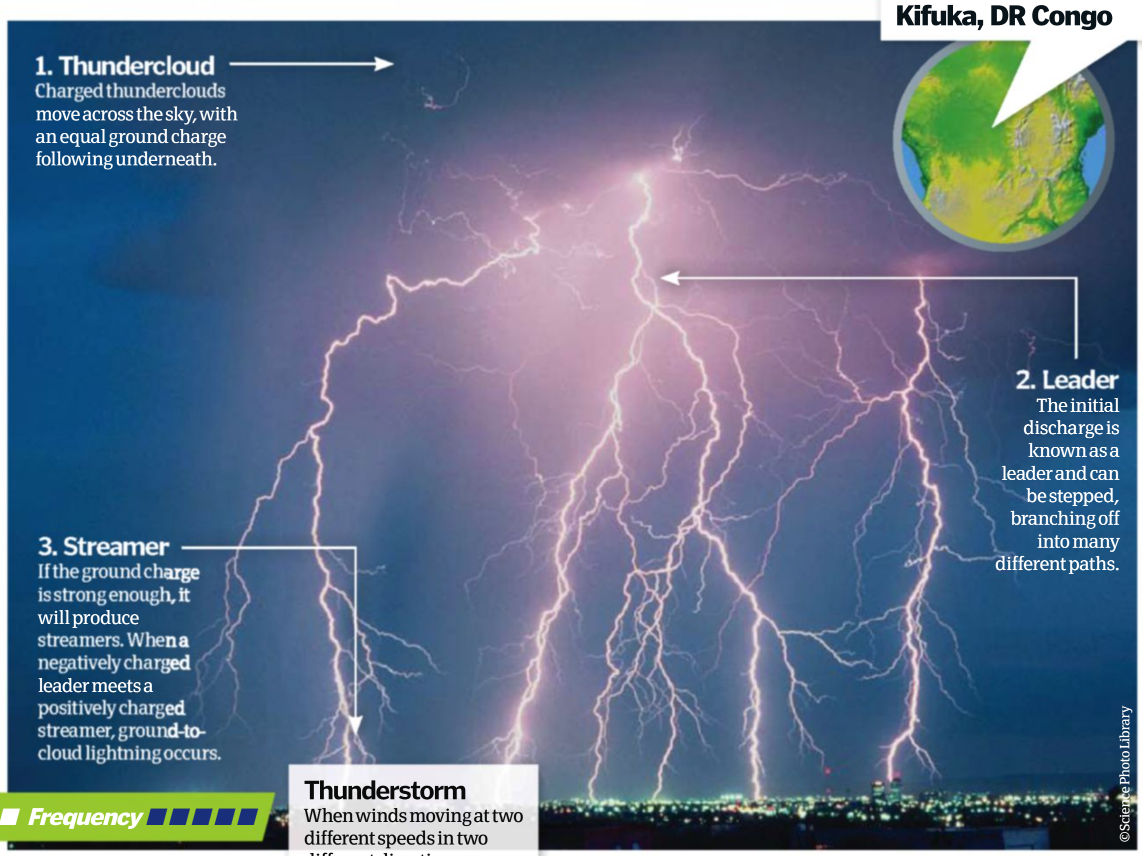
3. 1931 Central China Floods
As many as 4 million people lost their lives as a result of heavy flooding of the Yangtze River in 1931.

DID YOU KNOW? Governments may under-report death tolls to reduce criticism over lack of preparation

Lightning

Lightning is a discharge of atmospheric electricity that occurs during thunderstorms, resulting in an amazing display of light and sound. Lightning can be as hot as 30,000°C (54,000°F) and travel up to 200,000km/h (124,000mph). Scientists aren't entirely sure how lightning forms, but it may have to do with ice within the clouds forcing apart the positively and negatively charged molecules. Lightning bolts rapidly heat and expand the air around it, creating a shock wave that we hear as a loud thunder clap.

Cloud-to-ground lightning strikes can cause severe injuries or death. It can occur anywhere in the world other than Antarctica, but it is most seen in the tropics. Less than a quarter of all lightning bolts reach the ground, but these lightning strikes do result in about 240,000 injuries per year – a tenth of which result in death.



Most likely to find it here…
Kifuka, DR Congo

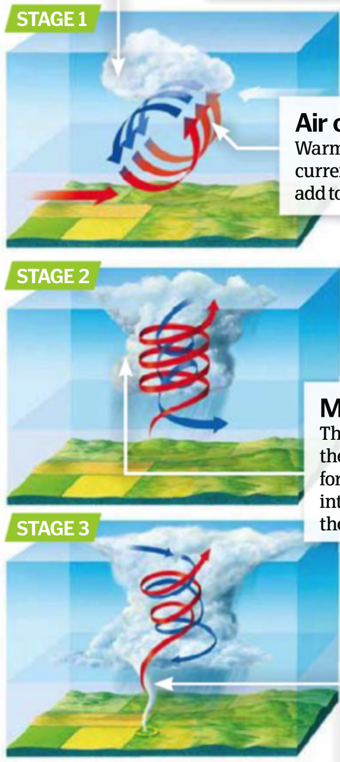
Danger *Destruction* *Frequency*

Thunderstorm
When winds moving at two different speeds in two different directions converge in a thunderstorm, they begin to cycle.

Tornadoes

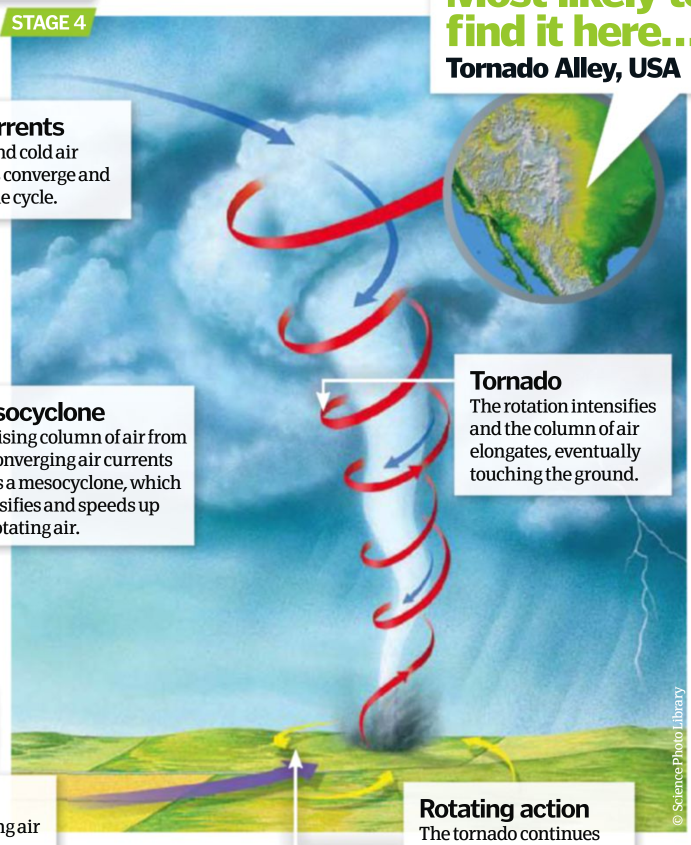
These storms are some of nature's biggest killers – rotating, violent columns of air that touch both the clouds and the Earth. Most tornadoes look like funnels, with the narrow end making contact with the ground. They can have wind speeds of up to 480km/h (300mph) and be dozens of kilometres wide. Most tornadoes travel across the ground for a short distance before breaking up, but not before they cause considerable damage. The United States experiences the majority of the world's tornadoes in the summer, although they have been seen on every continent but Antarctica.

Tornadoes can easily remove entire houses and bridges, shredding and twisting them into pieces. On the Enhanced Fujita Scale, the weakest (or EF1) tornadoes are very short-lived, where the most violent (EF5) can completely shred buildings and strip asphalt from road beds. People can die in any type of tornado if they don't have adequate shelter, but EF5 tornadoes – of which there are fewer than one per cent on average – have the most fatalities.



Air currents
Warm and cold air currents converge and add to the cycle.

Mesocyclone
The rising column of air from the converging air currents forms a mesocyclone, which intensifies and speeds up the rotating air.



Most likely to find it here…
Tornado Alley, USA

Tornado
The rotation intensifies and the column of air elongates, eventually touching the ground.

Danger *Destruction* *Frequency*

Air column
The cycle of rotating air and the mesocyclone force a column of air to break away.

Rotating action
The tornado continues along the ground, leaving devastation in its wake.

How do water striders walk on water?

The aquatic insect that uses water tension to stay on top

Found in freshwater ponds and still bodies of waters, the water strider, or pond skater, is a predatory aquatic insect that uses the highly sensitive water-repellent hairs on its legs to detect the vibrations of an insect as it falls into the pond. The strider will then race to the location to nab its prey. Despite being denser than water, a water strider doesn't sink; instead it exploits the principle of water tension to stay on the surface.

The forces of attraction between all the molecules in the water pull the molecules at the surface together so that they lock like a thin elastic membrane of slightly denser molecules. The water strider can then cross the surface without sinking.

Water striders have three pairs of legs, the front pair of which are short and dextrous enough to clasp, kill and eat small prey. The middle pair of legs, lying flat on the water, are used as oars to 'row' over the surface while the rear pair act like rudders for steering. Long, splayed legs enable the pond skater to distribute its weight evenly over a greater surface area, further helping it to float.

© R Wampers 2004

The archerfish explained

The fish that thinks it's a water pistol

Found in the mangroves and brackish waters of southeast Asia and northern Australia, the archerfish is known for its ability to capture aphids and other tiny insects from branches overhanging the water's edge with a highly accurate jet of water from its mouth.

First the archerfish sneaks up on its land-based prey, aided by its thin body and black-and-white vertical striped skin that blends with the mottled swamp light. Next it takes aim at the insect, and presses its tongue against a groove in the roof of its mouth to create a channel through which a fast jet of water can escape. By rapidly closing its gills, the fish produces this accurate stream of water that reaches 1.5m (5ft) to knock the insect into the water to be eaten. The archerfish uses the tip of its tongue to aim the jet, and for added accuracy it can boast a pair of large, binocular eyes located near its mouth. To allow for the fact that the location of the prey is distorted by refraction (light from the prey travels first through the air and then through the denser water), the archerfish has also learned to adjust its aim accordingly, targeting just below the victim.

DID YOU KNOW?

The poison of the black widow spider is 15 times stronger than a rattlesnake's venom. It rarely bites humans and although painful, less than 1% of them cause human death.

Black widows

How do these deadly spiders kill their prey?

The black widow spider (genus Latrodectus) begins by using its silk glands (spinnerets) at the rear of its abdomen to create a sticky web. It waits at the edge of the trap until its prey either flies or walks into it.

When an insect is trapped in the web, the black widow can sense the vibrations caused by the struggling prey. From these vibrations it can tell how big and strong the prey is, and if it is too big, it will leave well alone.

If the prey is small enough, however, the black widow will use its spinnerets to cover it in stronger webbing. It then firmly holds the prey with its chelicerae, which is a pair of hollow appendages above its mouth that send poison into the victim.

The spider's latrotoxin, neurotoxic poison causes the prey to suffer spasms, paralysis and death within ten minutes. After this, enzymes inside the victim liquefy its body allowing the spider to feed on it.

5 TOP FACTS PANGAEA FACTS

Rodinia
1 Pangaea isn't the first supercontinent. Rodinia, which broke up 750 million years ago, could have triggered runaway cooling, smothering the Earth in ice 1km (0.62 miles) thick.

In a name
2 Pangaea comes from pangala, which means 'all lands' in Greek. German meteorologist Alfred Wegener named it in 1912 when he proposed the theory of continental drift.

Mass extinction
3 Pangaea's formation could have wiped out 96 per cent of life. The supercontinent had a hot, dry interior and short, fertile coastline compared to today's continents.

Splendid isolation
4 Pangaea's break up led to Madagascar evolving numerous unique species. The island's species have been marooned in the Indian Ocean for 88 million years.

Land speed
5 India sped towards Eurasia at a record 15-20cm/year – about the speed that hair grows – during the Cretaceous period on its northward trek from the fragments of Pangaea.

DID YOU KNOW? *Dinosaurs lived in Antarctica about 200 million years ago when the continent was nearer the equator*

Supercontinent

Discover how the giant continent of Pangaea spanned the prehistoric Earth

An atlas from 255 million years ago would be almost unrecognisable. A supercontinent called Pangaea straddled the equator and stretched from the North to South Poles. Around 180 million years ago, Pangaea began fragmenting into today's continents. As the continents moved, new oceans and ocean currents formed.

Pangaea formed and split due to plate motion. The Earth's crust is broken into plates that drift across the mantle – hot, treacly rock lying between the solid crust and the molten core. Currents in the fluid mantle rising, flowing horizontally and sinking move the plates and the continents on top of them.

Among early evidence for moving continents were the remains of similar plants and animals along the coastlines of South America and Africa – now separated by the Atlantic Ocean. These species had spread across Pangaea. The jigsaw-like fit of South America and Africa's coastlines was another clue that they were once joined.

Pangaea Ultima

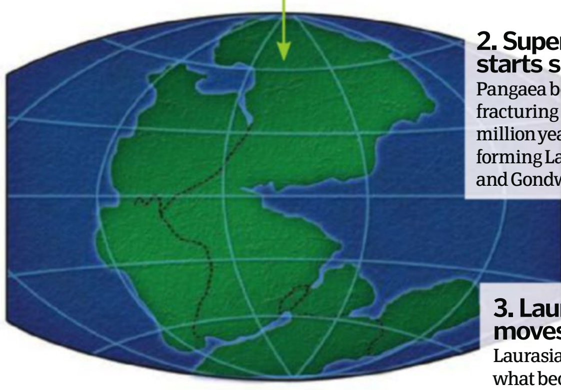
Volcanoes, earthquakes and the Himalayas are reminders that the continents are moving. Based on today's plate movements, within 50 million years Africa will collide with Europe, closing the Mediterranean and Red Sea and creating Himalayan-scale mountains extending from Spain into Asia.

In about 150 million years, the Atlantic Ocean floor will begin sliding beneath the Americas. When today's Mid-Atlantic Ridge, separating the North American and Eurasian plates, descends into the Earth's interior, the Atlantic will close. In 250 million years' time, Africa and America will have collided. A new supercontinent, 'Pangaea Ultima', will enclose a remnant of the Indian Ocean.

Pangaea to present

Pangaea began breaking apart around 200 million years ago. Scientists believe heat built up in the mantle under the supercontinent, causing the Earth's crust to bulge, stretch, weaken and rupture into new plates. The supercontinent split in three phases, approximately 180 million, 140 million and 55 million years ago.

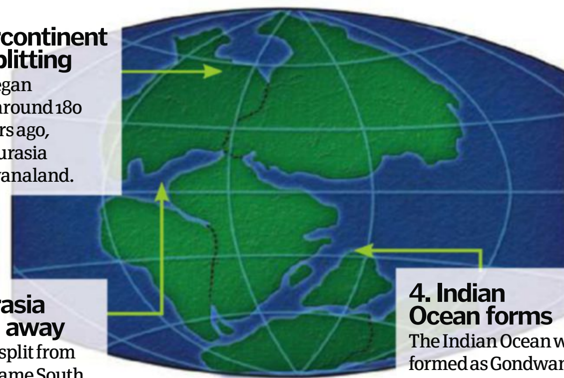
1. Pangaea forms
Pangaea began forming through continental collisions around 390 million years ago and was almost complete by 250 million years ago.



PERMIAN
250 million years ago

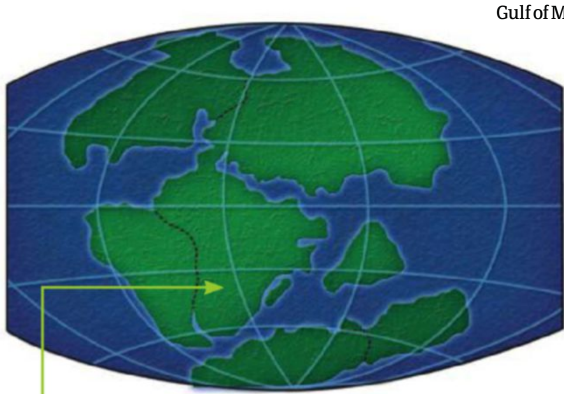
2. Supercontinent starts splitting
Pangaea began fracturing around 180 million years ago, forming Laurasia and Gondwanaland.

3. Laurasia moves away
Laurasia split from what became South America and Africa, opening up the central Atlantic and Gulf of Mexico.

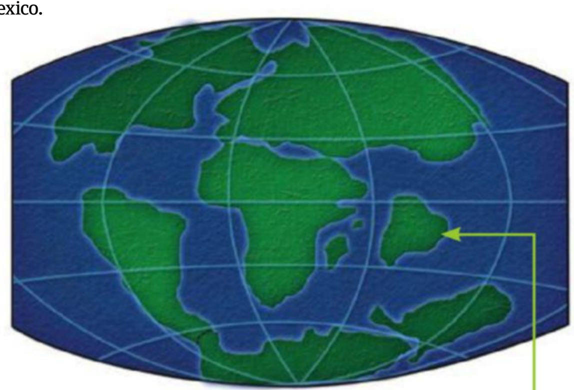


TRIASSIC
206 million years ago

4. Indian Ocean forms
The Indian Ocean was formed as Gondwanaland fragmented into India, Africa, Antarctica and Madagascar.



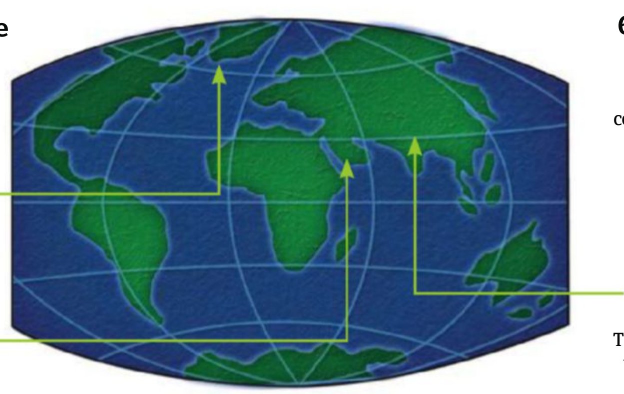
JURASSIC
145 million years ago



CRETACEOUS
65 million years ago

5. Second break-up phase
Plate movements starting around 140 million years ago began 'unzipping' South America from Africa and opening the southern Atlantic Ocean.

6. India heads north
India separated from Antarctica and raced northwards on a collision course with Eurasia, leaving Madagascar marooned in the Indian Ocean.



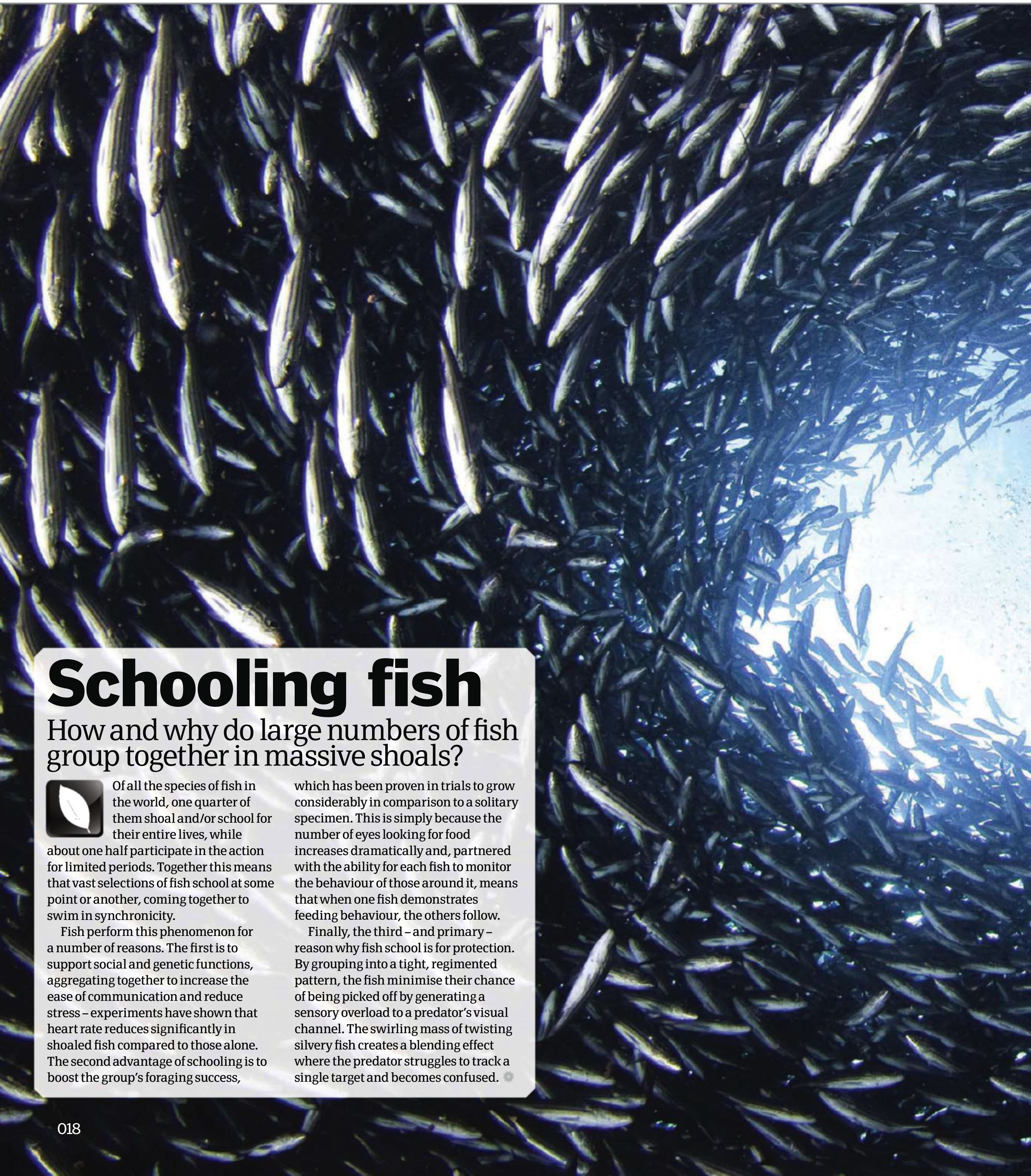
PRESENT DAY

7. Third breakup phase
During the third, final phase of Pangaea's break up around 55 million years ago, North America and Greenland split from Eurasia.

8. Himalayas form
India slammed into Asia. The collision thrust up rocks to form the Tibetan Plateau and gigantic Himalayan mountain range.

9. Red Sea forms
Plate movements during the last 20 million years have split Arabia from Africa to form the Red Sea.

Why some fish like to stick together…



Schooling fish

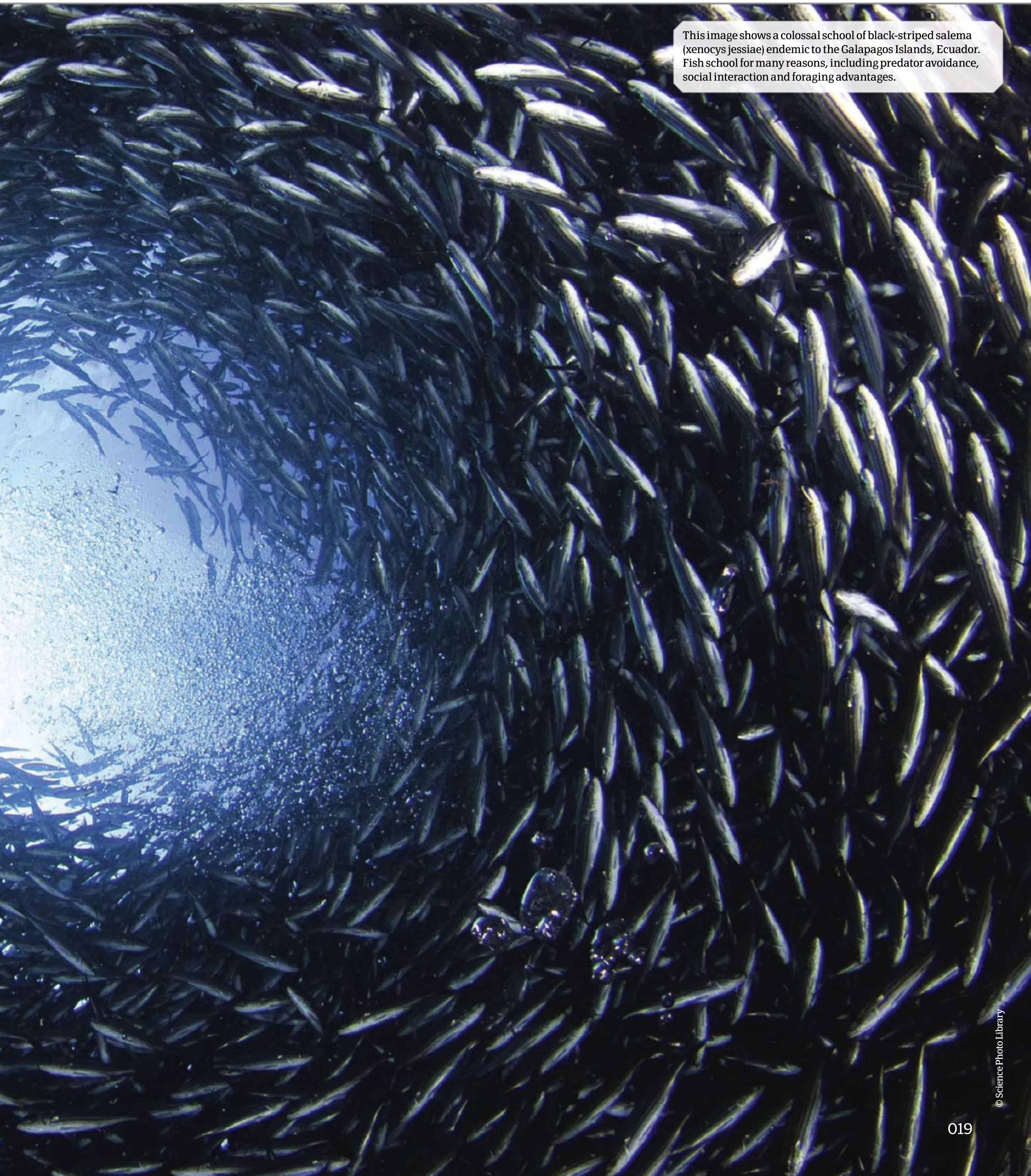
How and why do large numbers of fish group together in massive shoals?

Of all the species of fish in the world, one quarter of them shoal and/or school for their entire lives, while about one half participate in the action for limited periods. Together this means that vast selections of fish school at some point or another, coming together to swim in synchronicity.

Fish perform this phenomenon for a number of reasons. The first is to support social and genetic functions, aggregating together to increase the ease of communication and reduce stress – experiments have shown that heart rate reduces significantly in shoaled fish compared to those alone. The second advantage of schooling is to boost the group's foraging success, which has been proven in trials to grow considerably in comparison to a solitary specimen. This is simply because the number of eyes looking for food increases dramatically and, partnered with the ability for each fish to monitor the behaviour of those around it, means that when one fish demonstrates feeding behaviour, the others follow.

Finally, the third – and primary – reason why fish school is for protection. By grouping into a tight, regimented pattern, the fish minimise their chance of being picked off by generating a sensory overload to a predator's visual channel. The swirling mass of twisting silvery fish creates a blending effect where the predator struggles to track a single target and becomes confused.

DID YOU KNOW? *Killer whales often work together to 'herd' shoals of fish to the surface. This is known as 'carousel feeding'*



This image shows a colossal school of black-striped salema (xenocys jessiae) endemic to the Galapagos Islands, Ecuador. Fish school for many reasons, including predator avoidance, social interaction and foraging advantages.

Although deserts are what most people think of when you mention sand dunes, they can form anywhere

Sand dunes

What can be star or moon-shaped, hundreds of metres high and can swallow villages?

A few years ago, one village on the edge of north China's Gobi Desert was anxiously awaiting a silent invasion of their houses and farmland. Sand dunes were marching towards them at 20 metres per year. Within two years, the first houses vanished beneath the sand. More than 99 per cent of the world's active sand dunes are found in deserts, but they can form anywhere there is little vegetation, a wind or breeze to move loose sand, and obstacles – rocks, bushes or even dead animals – that cause a patch of sand to settle. This includes beaches, dried-up lakes and river beds.

Once a sand patch forms, it traps sand grains as they bounce along in the wind. Around 95 per cent of sand grains move by jumping a few centimetres into the air and landing a few metres away in a process called saltation. When grains hit the ground, they collide with other grains and make them saltate. Sand grains build up on the patch until it forms a pile – a sand dune. The dune reaches its maximum height when sand is eroded from the crest at the speed it's deposited, ensuring a constant height.

Wind erosion sculpts the upwind side of the pile into a gentle slope. The sheltered lee side of the dune – the slip face – is steepened by turbulent, backcurling eddies that form when the wind overshoots the dune crest. Dunes advance because sand is constantly removed from the windward side of the dune, carried over the crest, and dropped on the lee side.

When the prevailing wind is coming from a single direction, dunes have a slip face and a windward slope at right angles to wind direction. More complex dunes are formed where the wind changes direction. The biggest are some 300 kilometres (186 miles) long and up to 500 metres (1,640 feet) high, while the tiniest are under 5 metres (16 feet) long.

Dunes become inactive when the climate gets wetter. Plant roots bind the sand together, preventing dunes from growing and moving. Vegetated dunes in once-dry areas have slopes facing into long-gone winds.

A constellation of dunes

Dunes can be shaped like crescent moons, stars and Arabian swords. Their shape and size depends on wind direction, sand supply, vegetation and whether there are large obstacles where sand can collect. When the wind blows mainly from a single direction and there's abundant sand, transverse and barchanoid dunes form. These become barchan dunes if sand supply declines downwind. Linear dunes are found when prevailing winds coming from two similar directions meet. Winds that switch direction throughout the year produce star dunes. Parabolic dunes form if the plants on vegetated dunes are removed by grazing animals, for example.

Plant growth can render dunes inactive, locking them in place

Head to Head SAND DUNES

TALL

1. Sossusvlei, Namib Desert
Atlantic Ocean winds have shaped orange-coloured coastal dunes up to 300m (980ft) tall in the Sossusvlei region of Namibia.

TALLER

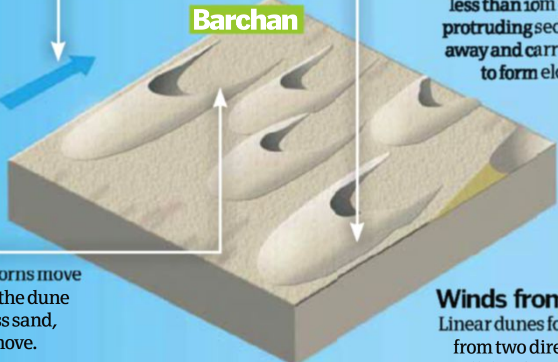
2. Badain Jaran Desert, China
Dunes in the windy Badain Jaran desert – some 500m (1,640ft) high – don't blow away because they're glued together by water.

TALLEST

3. Cerro Blanco, Peru
Earth's tallest dune stands a whopping 2,076m (6,811ft) above sea level and was sacred to Peru's ancient Nasca people.

DID YOU KNOW? Some dunes croak, whistle, bark, boom or belch when disturbed. These are found in around 30 places worldwide

Barchan

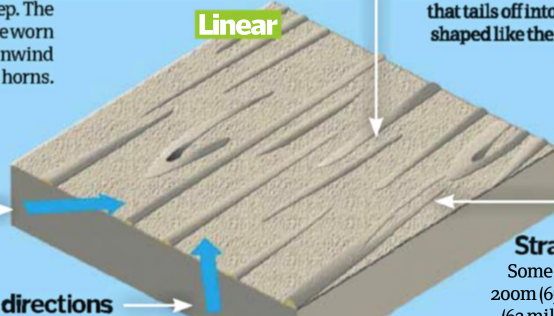


Prevailing wind
Crescent-shaped barchans form where the wind blows mainly from one direction. These travel rapidly at up to 30m (100ft) per year.

Eroded ridge
Barchans form where sand is less than 10m (33ft) deep. The protruding sections are worn away and carried downwind to form elongated horns.

Horns
The downwind-facing horns move faster than the centre of the dune because they contain less sand, making them easier to move.

Linear

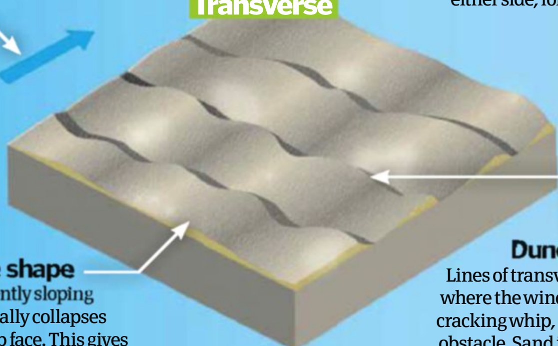


Seif dunes
Seif dunes are a sinuous, short linear dune that tails off into a spike downwind. They're shaped like the Arabian curved sword from which they get their name.

Straight, sinuous shape
Some linear dunes are long ridges 200m (656ft) high that run for 100km (62 miles) downwind, occasionally joining up at Y-shaped junctions.

Winds from two directions
Linear dunes form when winds meet from two directions. Sand travels parallel to the crest and tumbles down either side, forming two slip faces.

Transverse

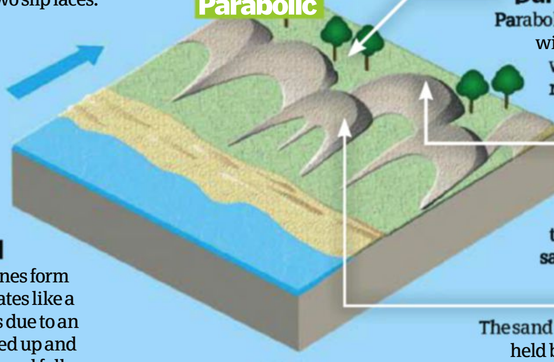


Wind direction
Transverse dunes form where the wind comes from one direction. They have a single slip face and the crest is at right angles to wind direction.

Simple, wave-like shape
Sand is carried up the gently sloping upwind side and eventually collapses down the downwind slip face. This gives them a simple, wave-like shape.

Dune field
Lines of transverse dunes form where the wind undulates like a cracking whip, perhaps due to an obstacle. Sand is scooped up and dropped as the air rises and falls.

Parabolic

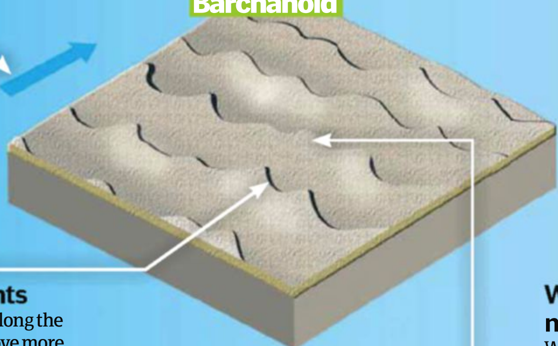


Dune moves downwind
Parabolic dunes are U- or V-shaped, with their arms facing into the wind. The centre of the dune moves in the wind direction.

Blowout
When plants are removed, their roots no longer hold and moisten the sand. The wind dries the sand and blows it downwind.

Fixed arms
The sand to the sides of the blowout is held by plants. As the sand moves downwind, the vegetated sand trails behind as long arms.

Barchanoid

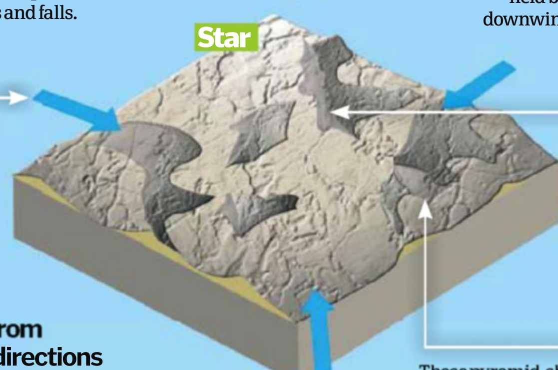


Wind direction
These are formed where the wind blows mainly from one direction and starts corkscrewing over bumps on the ground.

Neighbouring, joined-up crescents
The wind speed varies along the crest. Faster winds remove more sand, lowering and accelerating parts of the dune. A snaking ridge forms with protruding and recessed sections.

Further ridges downwind
The dune changes the airflow around it. This creates more corkscrews that shape the next dune.

Star



Wind from many directions
Where strong winds rotate through several directions on an annual cycle, star dunes form. They remain almost stationary because the wind isn't constant enough to blow them along.

Large size
Star dunes grow upwards because the changing winds pile up the sand. Star dunes in China's southeast Badain Jaran Desert can be 500m (1,640ft) high.

Pyramid shape
These pyramid-shaped dunes have slip faces pointed in different directions, and several irregular arms. Rarer than transverse or linear dunes, they are common in the northeastern Sahara Desert.

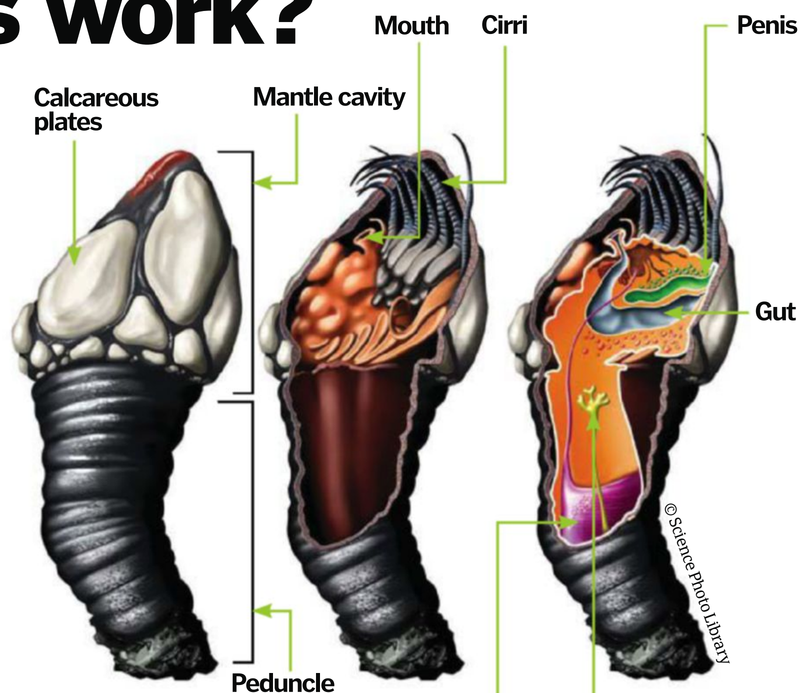
How do barnacles work?

How do these crustaceans survive in the same spot for nearly all their lives?

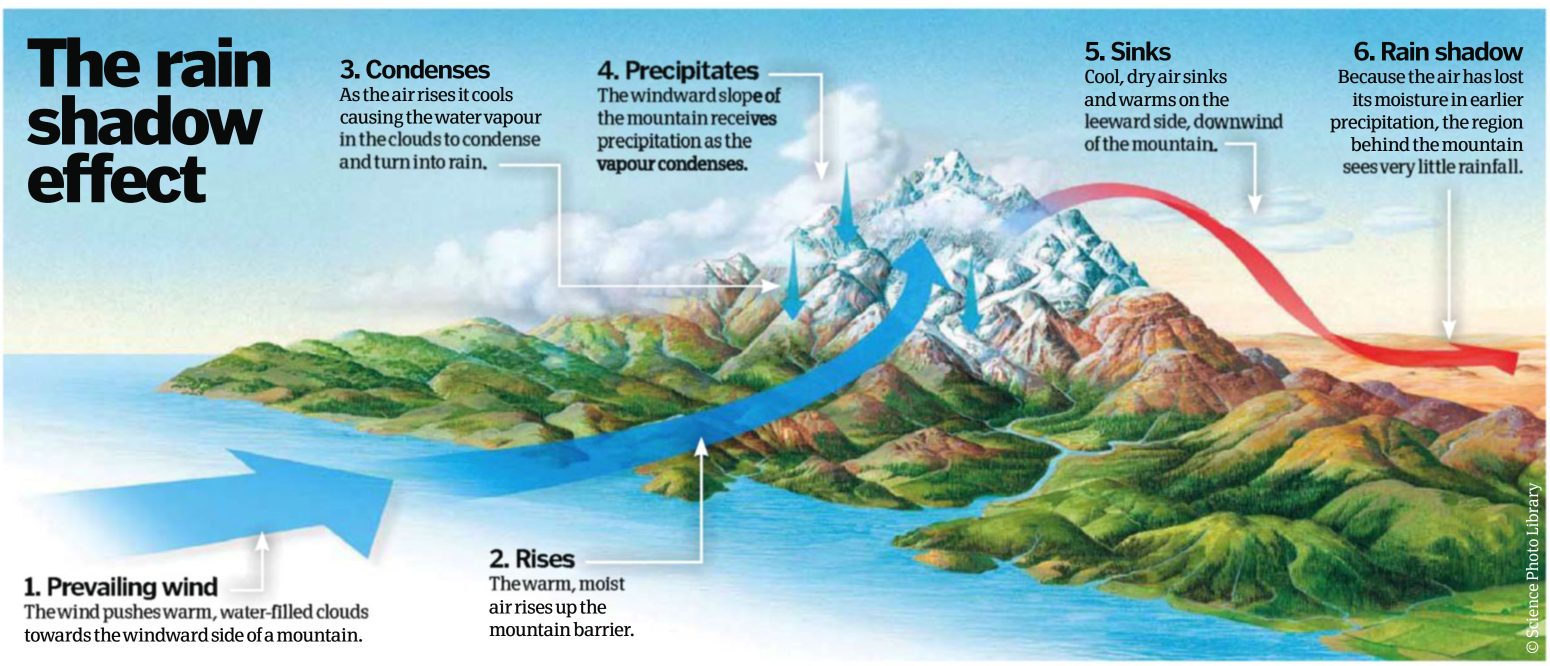
A barnacle starts out life as a small larva drifting around until it's ready to move into adulthood. At this point, the barnacle resigns itself to a life of immobility by attaching itself to a rock, a boat, or some other large object like a whale. It will then live out its days in the same spot, feeding on particles that float past in the water, such as plankton. The barnacle is a suspension feeder: that is, it uses its wispy, hair-like antennae to catch and filter particles that float by in the water. This process is often good for cleaning the water.

An adult barnacle will stay in the same place for the whole of its three to five-year lifespan. This is due to the very strong cement it uses to fasten itself to an object. In the long, thin peduncle section of the barnacle's body is a cement gland that produces this incredibly adhesive substance.

As you can imagine, being stuck in the same position for their entire lives means that barnacles don't 'get out' much. Each must therefore mate with its nearest neighbour. Despite being a hermaphroditic species (which means they have both male and female reproductive organs) barnacles still have to reproduce with each other. So how exactly do they get around the issue of being fixed to the spot? Well, they are endowed with incredibly long and stretchy penises.



The goose barnacle



Rain shadows

Why does this weather phenomenon cause deserts to form on one side of a mountain?

A rain shadow is an area that receives very little precipitation due to a substantial obstruction, most commonly a large mountain.

Such an obstruction blocks the path of moisture-rich rain clouds. Due to a process of cooling and condensation, a shadow area of dry conditions is likely to develop beyond this barrier.

Essentially this means that the windward side of a mountain receives plenty of precipitation where as the leeward side might be left extremely dry. This can result in a dramatic contrast of conditions with the formation of a desert on one side but not the other. The warm, dry breeze that blows down the leeward side of a slope is known as a foehn wind.

Termite mounds

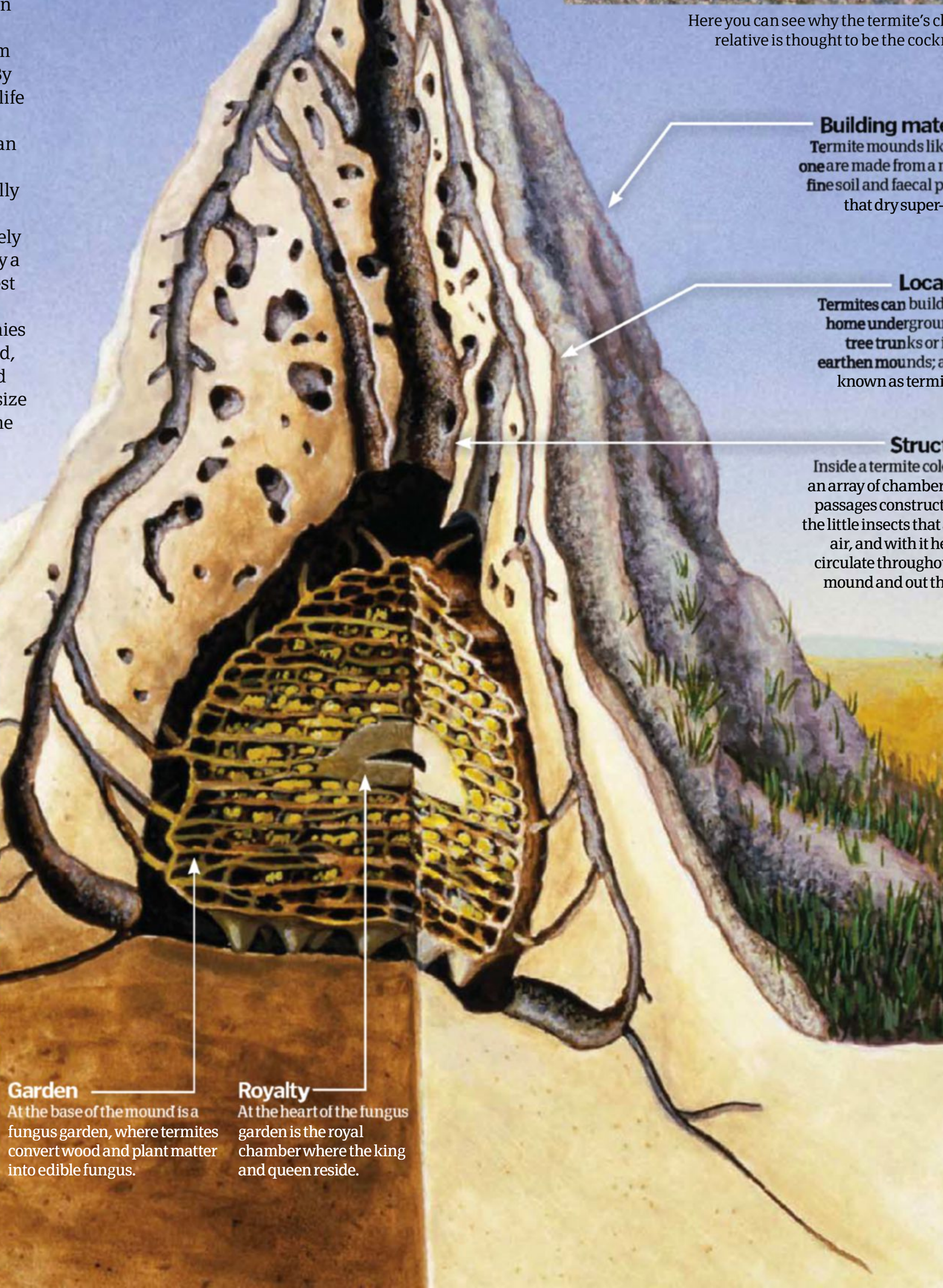
How does the wood-loving termite construct its home?

Termites are cellulose-eating insects that share many similarities with ants and bees, although, perhaps surprisingly, their closest relative is believed to be the cockroach. There are about 2,750 species of termite around the world, living in habitats as varied as tropical forests and the African savannah, through to the Pacific coast.

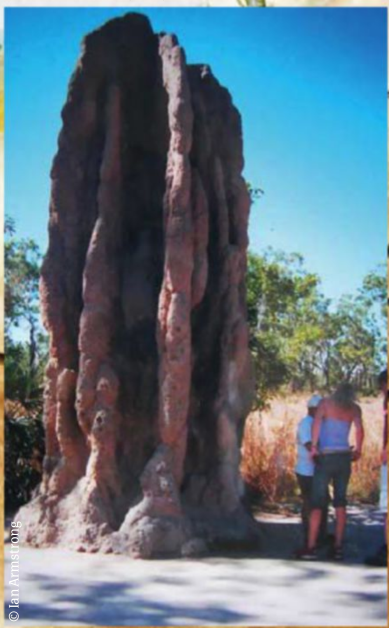
The eating habits of termites make them very important insects in an ecosystem. By consuming wooden structures and plant life they help convert dead trees into organic matter to trigger new life. However, this can cause problems, as they can eat through structural supports in buildings, eventually leading to their collapse.

Termites have evolved to eat wood largely because few other animals can; they carry a special bacteria that enables them to digest the tough cellulose fibres. This innate survival mechanism means termite colonies can be around for a very long time – indeed, some last up to 100 years. A termite mound (or termitarium) will reach its maximum size after four to five years, when it can be home to as many as 200,000 inhabitants.

Here you can see why the termite's closest relative is thought to be the cockroach



Some termite mounds can reach as tall as 9m (30ft)



SUPER VOLCANOES

Deadlier than an asteroid strike, these massive formations have the potential to destroy civilisation

Many will remember the airport chaos in 2010 when Eyjafjallajökull, one of Iceland's largest volcanoes, erupted after almost two centuries of slumber.

But though it might be hard to believe, considering the mammoth amount of disruption that it caused, the Icelandic eruption was tiny compared to a super-eruption's devastating power. The Eyjafjallajökull event measured a mere 4 on the Volcanic Explosivity Index (VEI), which rates the power of eruptions on an eight-point scale. A massive VEI 8 blast, on the other hand, would threaten human civilisation. Such a super-eruption would spew out more than 1,000 cubic kilometres (240 cubic miles) of ejecta – ash, gas and pumice – within days, destroying food crops, and changing the world climate for years.

A super-eruption hasn't happened in recorded history, but they occur about every 10,000-100,000 years. That's five times more often than an asteroid collision big enough to threaten humanity. Scientists say there's no evidence that a super-eruption is imminent, but humans will face nature's ultimate geological catastrophe one day.

A supervolcano is simply a volcano that's had one or more super-eruptions in its lifetime. Supervolcanoes are typically active for millions of years,but wait tens of thousands of years between major eruptions. The longer that they remain dormant, the bigger the super-eruption. They typically erupt from a wide, cauldron-shaped hollow called a caldera, although not every caldera housesa future supervolcano.

The supervolcano simmering under Yellowstone National Park in the USA is probably the world's most studied, but super-eruptions occur so rarely that they remain a mystery. We know of 42 VEI 7 and VEI 8 eruptions in the last 36 million years, however, much debris from ancient super-

5 TOP FACTS SUPERSIZED VOLCANOES

Mysterious
1 Some of Earth's supervolcanoes remain undiscovered. A mystery eruption in Ethiopia, for example, dumped 4,150km^3 (996mi^3) of debris in eastern Africa and the Red Sea.

Mass murderers
2 Some claim the Lake Toba eruption about 74,000 years ago almost drove humans extinct by plunging Earth into a volcanic winter. Only 3,000-10,000 people survived it, they believe.

Made in 2000
3 The word 'supervolcano' was coined in 2000 by BBC science documentary *Horizon*. The word is now used to describe volcanoes that produce gigantic, but rare, eruptions.

Maybe not
4 The odds of a Lake Taupo-sized super-eruption – that is, more than 1,000km^3 (240mi^3) of ash – this century are less than lightning striking your friends and family.

Massive
5 Supervolcano eruptions are dwarfed by Earth's largest lava flow, the Siberian Traps, which flooded an area the size of Australia. Lava erupted here for more than a million years.

DID YOU KNOW? Water heated under Yellowstone causes the park's many geysers

Inside a supervolcano

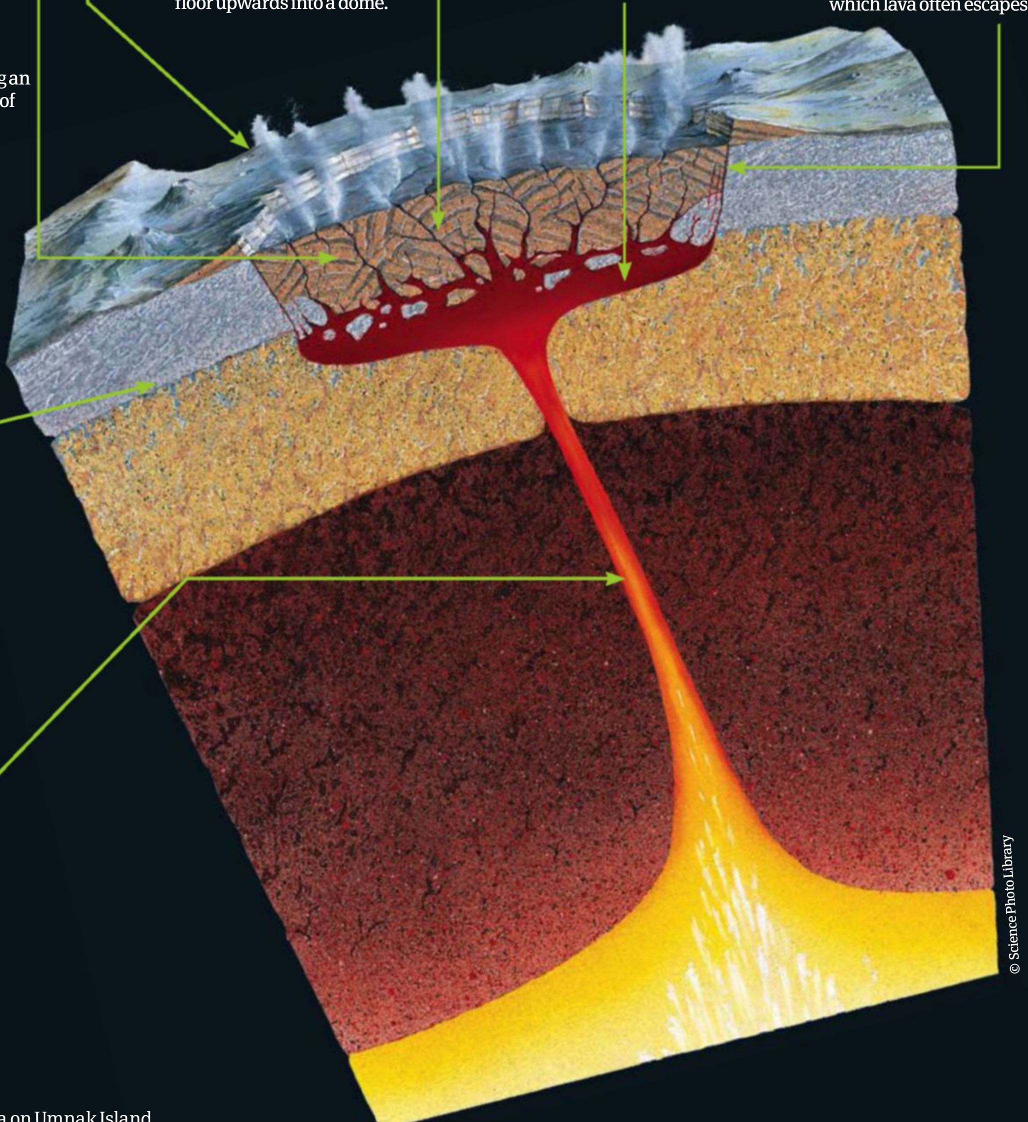
Hot springs
Snow and rain seep down through fractures in the Earth's crust and are superheated by magma close to the surface.

Caldera
This cauldron-shaped hollow forms when a supervolcano's magma chamber empties during an eruption and the rock roof above collapses.

Resurgent dome
Molten rock rising in the underground magma chamber pushes the overlying caldera floor upwards into a dome.

Shallow magma chamber
An underground pool of molten rock called magma, which vents to the surface as a volcanic eruption.

Ring fractures
A circular fracture running around the collapsed edge of the magma chamber through which lava often escapes.



Earth's crust
The Earth's crust is perhaps 56 kilometres (35 miles) thick under the continents and made of solid rock.

Magma
Magma is lighter than the Earth's crust and rises towards the surface where it erupts as a volcano.

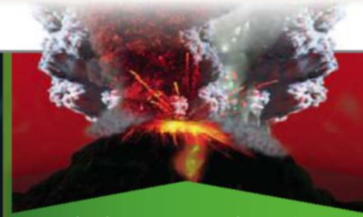
The Okmok Caldera on Umnak Island in Alaska is 9.3km (5.8mi) wide

Predicting the next super-eruption

Volcanologists at the Yellowstone Volcanic Observatory are among those studying supervolcanoes. They hope to have decades or centuries to prepare for a super-eruption. Warning signs could include the ground bulging and cracking as hot rock muscles to the surface, an increase in small eruptions and earthquakes, and changes in the gases escaping the ground.

Scientists analyse earthquakes by measuring ground vibration with seismometers. Earthquakes often increase before eruptions as magma and gas force through underground fractures, causing rocks to break. The ground historically rises before eruptions due to upwelling magma. For example, the north flank of US volcano Mount St Helens rose by a staggering 80 metres (262 feet) in 1980.

Scientists constantly keep track of Earth movements using networks of satellite GPS receivers. Like GPS in cars, these monitor the receiver's location on the ground. Another satellite technology, InSAR, measures ground movement over large areas once or twice annually.



8. CALDERA FORMS
DAYS
The rock cylinder inside the ring fractures and plunges into the emptied magma chamber. Gas and lava spurt from the fractures.

7. DEADLY CLOUDS
DAYS
The fractures join into a ring of erupting vents. Toxic ash and fragment clouds race downhill at snow avalanche speed.

6. SUPER-ERUPTION
HOURS TO DAYS
The expanding gases act like bubbles of pop in a shaken bottle, flinging lava and rock high into the atmosphere.

5. MAGMA CHAMBER RUPTURES
HOURS TO DAYS
Vertical fractures in the swollen crust breach the magma chamber, allowing pressurised, gas-filled magma to escape to the surface as lava.

4. WARNING SIGNS INCREASE
WEEKS TO CENTURIES
Warning signs of a super-eruption may include swarms of earthquakes and the ground rapidly swelling up like baking bread.

3. MAGMA CHAMBER EXPANDS
TENS OF THOUSANDS OF YEARS
Supervolcano magma chambers can grow for tens of thousands of years because they are surrounded by flexible hot rock.

2. PRESSURE BUILDS
TENS OF THOUSANDS OF YEARS
As magma accumulates in a chamber, the pressure builds and the cavity expands. Fractures begin to form in the chamber roof.

1. MAGMA RISES
TIME: MILLIONS OF YEARS
Magma forms when rock deep in the Earth liquefies and pushes through the solid crust towards the surface.

COUNTDOWN TO ERUPTION

This artist's illustration reveals the smoke and ash that could result from a supervolcanic eruption at Yellowstone

© Science Photo Library

The fallout following a super-eruption

A supervolcano erupting today could threaten human civilisation. Clouds of molten rock and iridescent gas travelling three times faster than motorway cars would obliterate everything within 100 kilometres (60 miles) of the blast. Dust would spread thousands of kilometres, blotting out the Sun. People's unprotected eyes, ears and noses would fill with needle-like ash, which can pop blood vessels in the lungs and kill by suffocation.

Up to 0.5 metres (1.6 feet) of ash could rain down each hour, collapsing roofs, poisoning water supplies and halting transport by clogging car and aircraft engines; just a few centimetres of ash can disrupt agriculture. The 1815 eruption of Indonesia's Mount Tambora caused the 'year without a summer' when European harvests failed, bringing famine and economic collapse. Financial markets could be disrupted and countries swamped by refugees. Some scientists say a Yellowstone super-eruption could render one-third of the United States uninhabitable for up to two years.

eruptions has worn away. Eruptions like these take place at irregular intervals and scientists are unsure what triggers them.

Supervolcanoes, like all volcanoes, occur where molten or partly molten rock called magma forms and erupts to the Earth's surface. All supervolcanoes break through the thick crust that forms the continents. The Yellowstone caldera sits on a hot spot, which is a plume of unusually hot rock in the solid layer called the mantle that lies below the Earth's crust. Blobs of molten mantle rise from the hot spot towards the surface and then melt the crustal rocks.

Other supervolcanoes like Lake Toba in Sumatra, Indonesia, lie on the edges of the jigsaw of plates that make up the Earth's crust. Near Sumatra, the plate carrying the Indian Ocean is being pushed underneath the crustal plate carrying Europe. As it descends, the ocean plate melts to form magma.

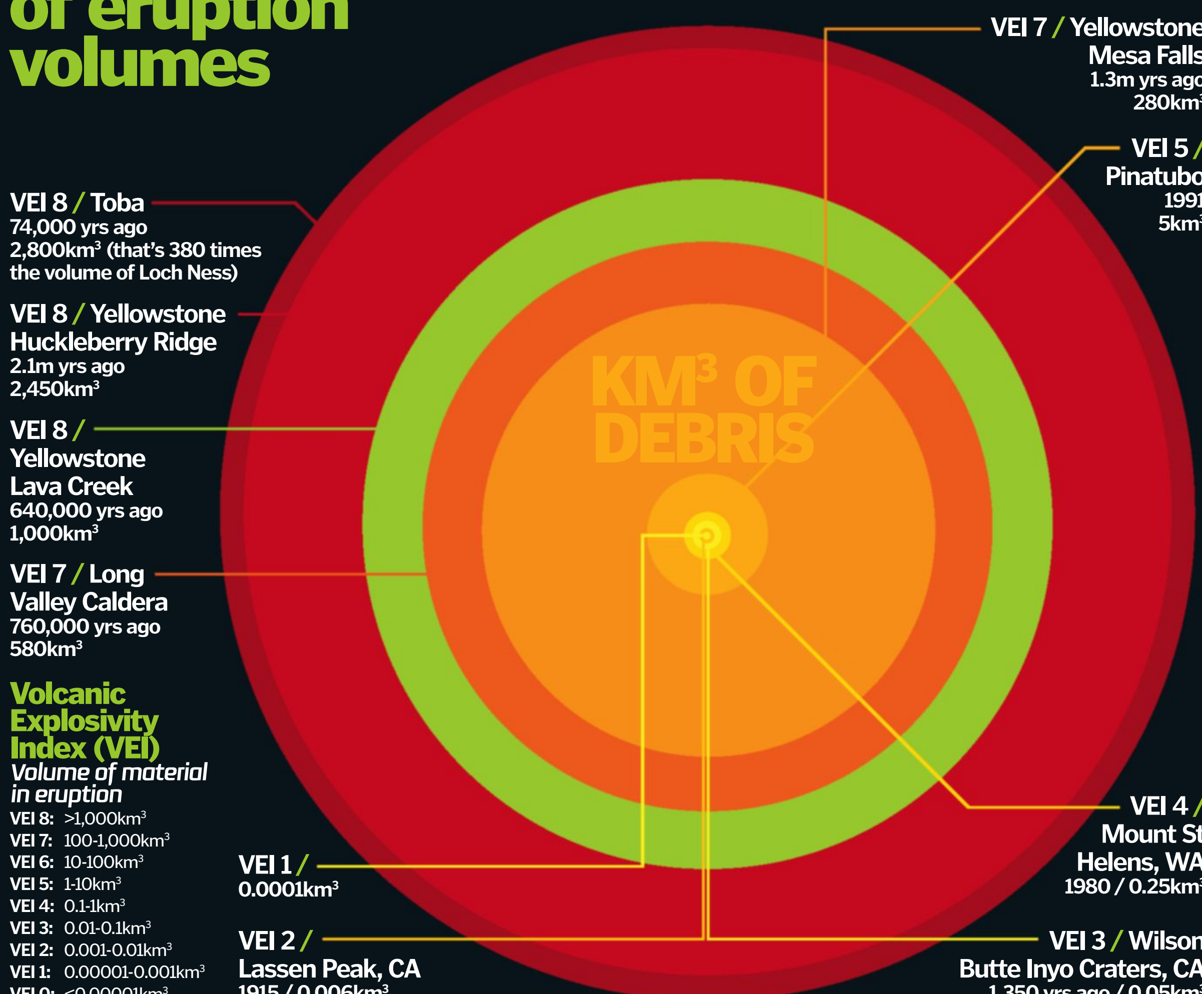
Vast quantities of magma are needed to fuel a super-eruption. Some scientists believe that supervolcanoes are 'super' because they have gigantic, shallow magma chambers that can hold volumes of up to 15,000 cubic kilometres (3,600 cubic miles) and grow for thousands of years. Magma chambers are underground pools of accumulated magma that erupt through cracks to the surface. Volcanoes with smaller chambers expel magma before enough pressure builds for a supersized event.

Some scientists speculate that hot and flexible rocks surround supervolcano magma chambers, allowing them to swell to accommodate more magma. The rocks are kept malleable by blobs of magma repeatedly welling up from below.

A super-eruption starts when the pressurised magma explodes through fractures in the chamber roof. The eruption is violent because supervolcano magma is rich in trapped gas bubbles, which expand and burst as it abruptly depressurises; the eruption is akin to uncorking a champagne bottle. The magma is also sticky and unable to flow easily because it's made partly from melted continental crust. This is in contrast to a volcano like Mauna Loa in Hawaii, which gently pours out lava because its magma is fluid and contains little gas.

Hot fragments and gas soar to heights of more than 35 kilometres (22 miles) and spread in the atmosphere. Some of the fragments drift down and blanket the ground like snow. Other hot fragments rush downhill for hundreds of square kilometres at speeds exceeding 100 kilometres per hour (62 miles per hour) as toxic, ground-hugging pyroclastic flows. The magma chamber rapidly drains during the super-eruption, causing the roof above to sink into the empty space to (re-)form a caldera.

Comparison of eruption volumes



Volcanic Explosivity Index (VEI)
Volume of material in eruption

- VEI 8: >1,000km³
- VEI 7: 100-1,000km³
- VEI 6: 10-100km³
- VEI 5: 1-10km³
- VEI 4: 0.1-1km³
- VEI 3: 0.01-0.1km³
- VEI 2: 0.001-0.01km³
- VEI 1: 0.00001-0.001km³
- VEI 0: <0.00001km³

BIG

1. Huckleberry Ridge Caldera
Yellowstone National Park, USA
Yellowstone's biggest eruption 2.1 million years ago blasted a hole in the ground around three times wider than Greater London.

BIGGER

2. Lake Toba
Sumatra, Indonesia
This eruption 74,000 years ago smothered south-east Asia in 15cm (5.9in) of ash and excavated the planet's largest volcanic lake.

BIGGEST

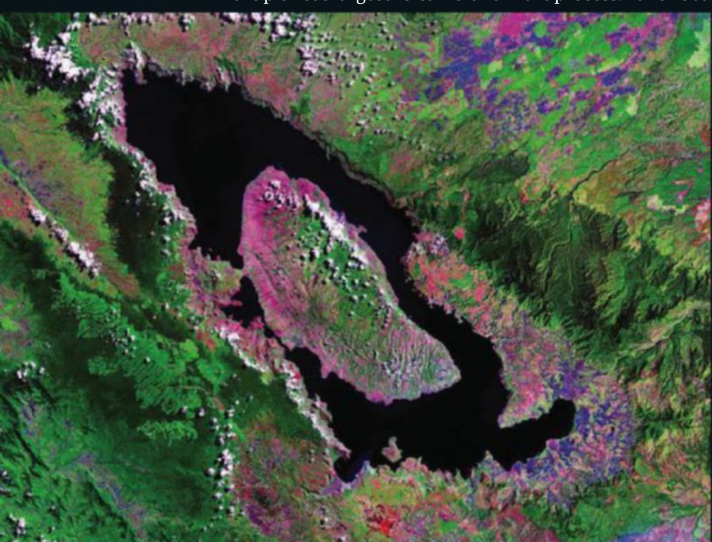
3. La Garita Caldera
Colorado, USA
Earth's biggest known super-eruption, which occurred approximately 28 million years ago, would have buried surrounding states in debris 12m (39ft) deep.

DID YOU KNOW? *Our solar system's most powerful volcano is Loki, which is located on Jupiter's moon Io*

VOLCANOES VS SUPERVOLCANOES
The explosive battle

	TYPICAL VOLCANO	TYPICAL SUPERVOLCANO
FOOTPRINT	Volcanoes vary, but a typical shield volcano might be 5.6km (3.5mi) across. The crater – equivalent to a caldera – of Mount St Helens, USA, is about 3.2km (2mi) wide.	Bigger calderas produce larger eruptions, meaning most supervolcanoes cover vast areas. Lake Toba is 90km (56mi) long and lies in such a caldera.
HEIGHT	Normal volcanoes are cone-shaped mountains perhaps 1km (3,280ft) high. Mount St Helens, for example, stands 635m (2,084ft) above its crater floor.	Supervolcanoes have 'negative' topography: they erupt from smouldering pits. Lake Toba, which lies in a supervolcano caldera, is over 0.5km (0.3mi) deep.
VOLUME	Typical volcanoes have smaller magma chambers. The magma chamber of Mount St Helens, for example, has a volume of just 10-20km³ (2.4-4.8mi³).	Yellowstone's magma chamber and caldera are similar in width. The chamber is 60 x 40km (37 x 25mi) wide, and 5-16km (3-10mi) below the surface.
EJECTA	Even huge volcanoes produce comparatively little debris; eg Yellowstone's super-eruptions were up to 2,500 times bigger than the 1980 St Helens blast.	Super-eruptions eject more than 1,000km³ (240mi³) of debris. They also spew at least 10^{15}kg (10^{12} tons) of magma: more than the mass of 50 billion cars.
DAMAGE	A few eruptions, like Mt Tambora in 1815, changed global climate, but most of the 20 volcanoes erupting as you read this affect only their immediate vicinity.	A Yellowstone eruption could drop the global average temperature up to 10°C (50°F) for ten years. Within 1,000km (621mi) of the blast, 90 per cent of people could die.

A super-eruption took place in Sumatra 74,000 years ago, forming the planet's largest volcanic lake in the process: Lake Toba



A satellite view of Yellowstone National Park, which is positioned above a hot spot in the Earth's crust

Geysers like Old Faithful at Yellowstone are heated by the supervolcano which lies beneath

Yellowstone's restless giant

Beneath Yellowstone National Park bubbles an active supervolcano. A magma chamber, lying as close as eight kilometres (five miles) to the surface in places, fuels the park's 10,000 jewel-coloured hot springs, gurgling mud pools, hissing steam vents and famous geysers like Old Faithful. The 8,897-square-kilometre (3,435-square-mile) park includes the volcano's caldera, which spans 4,400 square kilometres (1,750 square miles); that's big enough to cover the emirate of Dubai.

The supervolcano is fuelled by a 'hot spot', a plume of hot rock rising from hundreds of kilometres below the Earth's surface. Hot spots act like gigantic Bunsen burners, driving catastrophic eruptions by melting the rocks above them. Scientists remain uncertain why hot spots form; they're not found at the edge of Earth's crustal plates and most volcanic activity happens where these plates jostle against one another. Since the hot spot formed around 17 million years ago, it has produced perhaps 140 eruptions. The North American crustal plate has slid southwest over the stationary hot spot like a belt on a conveyor leaving a 560-kilometre (350-mile) string of dead calderas and ancient lava flows trailing behind.

There have been three super-eruptions since Yellowstone moved over the hot spot: 2.1 million, 1.3 million and 640,000 years ago. Each eruption vented enough magma from the volcano's storage reservoir to collapse the ground above into a caldera. The first and largest eruption created the Huckleberry Ridge Tuff, more than 2,450 cubic kilometres (588 cubic miles) of volcanic rock made of compacted ash. The eruption blasted a huge caldera perhaps 80 x 65 kilometres (50 x 40 miles) in area and hundreds of metres deep across the boundary of today's national park. The most recent caldera-forming eruption blanketed much of North America in ash and created today's Yellowstone Caldera. Hot gas and ash swept across an area of 7,770 square kilometres (3,000 square miles).

ON THE MAP

Six known supervolcanoes

1. Lake Toba, Sumatra, Indonesia
2. Long Valley, California
3. Lake Taupo, New Zealand
4. Valles Caldera, New Mexico
5. Aira Caldera, southern Japan
6. Yellowstone National Park, United States

How do blowholes work?

All images © SPL

Find out why marine mammals have a little hole on top of their heads

Whales, dolphins and porpoises are all cetaceans and spend their whole lives underwater. Unlike fish however, which have gills, cetaceans are mammals and so have lungs. They therefore need to come to the surface now and then to take in oxygen.

The blowhole is a small nostril-like opening that is located on the dorsal side of the mammal near its head. It is this that enables the animal to take in air without having to stop and lift its mouth out of the water.

A muscular flap covers the blowhole and remains sealed when the creature is relaxed so the lungs don't fill with water. When the animal contracts this flap, the blowhole opens enabling the creature to exhale and take in another breath.

Sperm whales can hold their breath for over an hour. When the whale comes to the surface, air and waste gases are forcefully expelled from the lungs. As this warm, moist air is released, the water vapour condenses and emerges from the blowhole as a misty spout.

A medical leech (hirudo medicinalis) feeding on a human hand

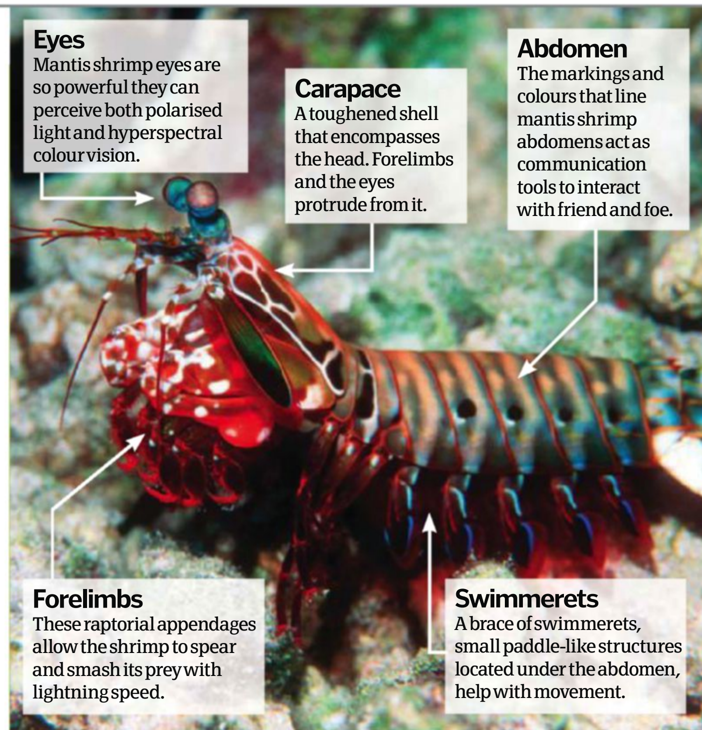
Leeches

How do these vampiric worms suck your blood?

A leech sucks your blood by first biting into the skin and then attaching its sucker around the wound. Once attached it secretes an anticoagulant enzyme (hirudin) into your bloodstream, which prevents the blood from clotting and allows the leech to draw it more easily. The leech sucks the blood into its digestive system, which includes a large pouch, where it can be stored for months.

Interestingly, certain leech species have in fact been used for clinical bloodletting for thousands of years, with records dating as far back as 500 BCE. Their use stemmed mainly from the ancient Greek humoral theory (good health is ensured by the balancing of the four humours: blood, phlegm and black and yellow bile), which remained prevalently practised throughout medieval Europe.

The species hirudo medicinalis has been most common for bloodletting historically, however other leeches of the same genus have also been utilised. Today, leeches are used sparingly in some countries to reduce tissue swelling and ease the passage of fresh, oxygenated blood to damaged areas of the body.



The world's fastest punch

Why the mantis shrimp is a fast and ferocious marine crustacean

Mantis shrimp, which are so named due to their resemblance to the praying mantis, are one of the most dangerous creatures in the ocean. Indeed, equipped with an incredible set of eyes comprising up to 10,000 separate apposition-type ommatidia and a pair of raptorial appendages capable of moving at the velocity of a .22-calibre bullet, they are apex predators, capable of smashing and cleaving their prey with brutal efficiency.

The statistics tell you all you need to know in order to realise the destructive capability of these crustaceans. The forelimbs – which come in two main varieties, club or spear-tipped – when unleashed move with an acceleration of 10,400 g, the equivalent of 102,000m/s^2 (335,000ft/s^2), and a speed of 23m/s (75ft/s) from origin. This rapidity is possible because the shrimp generate cavitation bubbles between the appendage and the striking surface that, when collapsed, produce instantaneous forces of 1,500 Newtons on contact as well as a secondary shock wave strike. Consequently, any snail, crab, mollusc or fish (all common in mantis shrimp diets) caught by a blow, will either be horribly skewered or clubbed with immense force.

In order to maximise their ability to strike prey, mantis shrimp eyes have developed into arguably the most advanced specimens in the world. Each eye, which is mounted on its own individual stalk, possesses trinocular vision and depth perception – the latter especially important for ranging their raptorial appendages. In addition, both eyes can perceive polarised light and hyperspectral colour vision, enabling the shrimp to finely distinguish their prey, which often is transparent or semi-transparent, in brightly coloured coral environments.

5 TOP FACTS SWIM BLADDERS

Tasty
1 In certain Asian cultures the swim bladders of large ocean fish are considered a tasty foodstuff, renowned as a delicacy that is commonly served braised.

Origin
2 Charles Darwin wrote: "There is no reason to doubt the swim bladder has been converted into lungs [and that] all vertebrates with true lungs are descended from an ancient prototype."

Hearing
3 In some fish the swim bladder is connected to the labyrinth of the inner ear by a bony structure from the vertebrae. This provides a precise sense of water pressure and hearing.

Gas
4 The mix of gases in swim bladders varies. Shallow-water fish bladders tend to approximate that of Earth's atmosphere, while deep-sea fish have higher oxygen mixes.

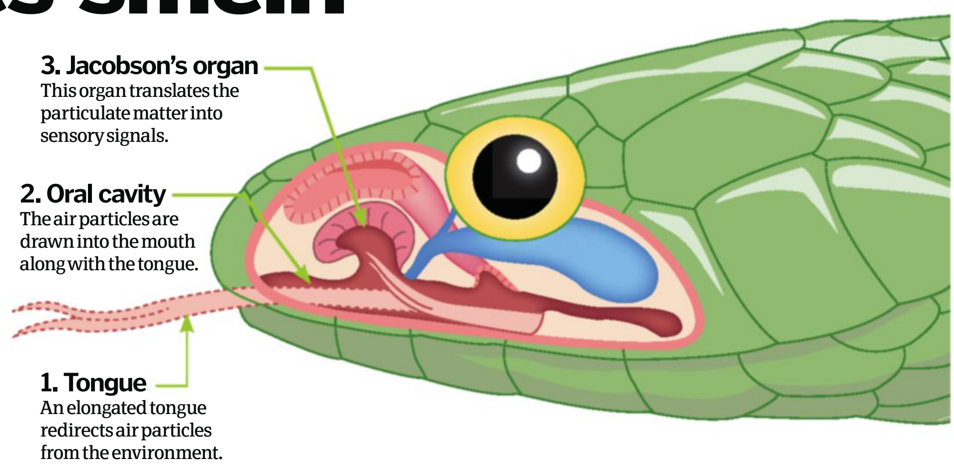
Bladder-free
5 Cartilaginous fish like sharks lack both lungs and swim bladders. This has led to postulation that both these organs developed 420 million years ago after such species divided from other fish.

DID YOU KNOW? *The dasyatis brevicaudata, or smooth stingray, can grow up to two metres (6.6 feet) wide*

How do snakes smell?

Nose not work? No problem!

While snakes have both nostrils and nasal cavities, they do not use them to smell with. In fact, snakes smell through the combination of a specialised organ located in their oral cavity and a flicking motion of their elongated tongue. The organ in question is referred to as the vomeronasal organ (or Jacobson's organ) and is located in the roof of their oral cavity. Due to its internal positioning, the snake utilises its forked tongue to flick air particles from the surrounding environment into contact with it. From here the vomeronasal organ translates the smell into electrical signals to be sent to the snake's brain, enabling it to determine whether prey or predators are in its locale. In addition, due to the tongue's role as a smelling device, it is not used by snakes to aid the swallowing process.




Stingrays are bottom-dwellers, often lying partially buried in sand and silt, which can make them a hidden danger to unsuspecting swimmers/divers

Stingrays explained

How do these spiny, flat-bodied fish which dwell on the seabed live?

Stingrays are flat-bodied rays most well-known for the sharp spines located in their tails. There are two main families of stingray: dasyatidae and urolophidae, each of which includes a wide range of the disc-shaped fish. Their size varies from around 25 centimetres (9.8 inches) in width – such as the dasyatis sabina species – through to over two metres (6.6 feet), as demonstrated by the Australian dasyatis brevicaudata. Stingrays inhabit the majority of Earth's oceans, from the North Atlantic through to the South Pacific.

Stingrays are bottom-dwellers, operating in the main close to the seabed. In fact they regularly camouflage themselves from predators by lying dormant on the seabed partially covered in sand and silt. This can make them particularly difficult to spot, especially for humans, and due to some species sporting spiny venomous tails, they can prove dangerous if accidentally provoked. Their diet mainly consists of sea worms and other small invertebrates, which they consume with their bottom-mounted mouth.

Most stingrays do in fact sport one or more barbed stings on their tail, which are modified forms of dermal denticles. It is possible for the stinger itself to grow to over 35 centimetres (13.8 inches) in length, and it is supplied with venom by a numberof glands that are positioned on its underside. The venom is concentrated over the stinger in a thin layer of skin.

How can a fish remain buoyant?

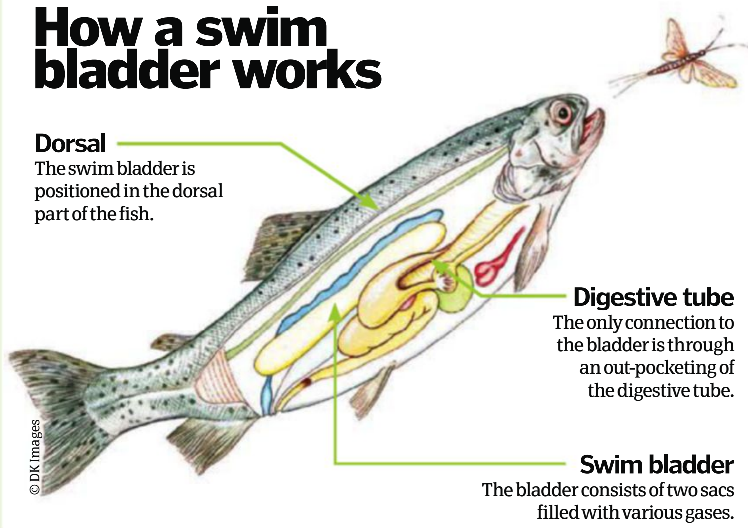
Learn how the swim bladder organ gives fish an internal ballast system

Swim bladders are buoyancy-aiding organs possessed by the majority of bony fish. The organ is located in the fish's body cavity and originates from an out-pocketing of the digestive tube. It is filled with a variety of gases including oxygen, carbon dioxide, argon and nitrogen and functions as a biological ballast system, allowing the fish to efficiently maintain its depth.

Swim bladder structure usually consists of two sacs located in the dorsal portion of the fish that, due to flexible walls, can expand or contract according to ambient pressure (ie depth). These flexible walls are commonly lined with guanine crystals in order to make them impenetrable to auxiliary gases and, as a consequence, are predominantly closed structures.

Gas to expand the swim bladder is produced by a dedicated gas gland. This works by excreting lactic acid to produce carbon dioxide. The resultant acidity then causes the haemoglobin in the fish's blood to shed its oxygen – a process that is known as the 'Root effect' – and diffuse partly into the bladder.

How a swim bladder works



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The statistics...

Snakes

Type: Reptile

Diet: Carnivorous

Average life span in the wild: Up to 25 years

Weight: 1.4-97kg (3-214lb)

Size: 0.1-9m (0.3-30ft)

Snakes

Feared and respected in equal measure throughout human civilisation, discover the incredible life of snakes

Snakes are not legless lizards. They evolved from lizards about 112 million years ago but have since changed their body shape and habits quite radically. Modern legless lizards, like the slow worm and grass lizard, have short bodies and long tails, but snakes are nearly all body with a relatively short tail on the end. This means that the skeleton of a snake has ribs running for most of its length. Snakes also lack eyelids and external ear holes. Their eyes are protected by an unblinking, transparent scale called a brille and their poor hearing is made up for by their other senses. Snakes can smell the air by collecting molecules on their forked tongue, then passing them back to the Jacobson's organ at the front of the mouth. They can also sense vibrations through the ground and some species have 'thermal imaging' that enables them to detect the infrared radiation from live prey, even in complete darkness. The coral snake (aipysurus laevis) has light receptors in its tail, so that it can check it hasn't left the tip poking out, when it hides in a dark crevice.

Snakes have scales to conserve moisture and allow them to grip the ground. These aren't loose, like feathers or skin, but are anchored to the deep layers of the epidermis. When a snake moults, it sheds the entire skin in one go. Moulting isn't to allow room for growth (as with insects), but a way of replacing worn scales and getting rid of parasites.

You can find snakes in tropical seas and on every continent except Antarctica, but there are a few islands that they have never conquered, including Iceland, New Zealand and, perhaps most famously, Ireland.

Snakes' jaws are adapted to swallow their prey whole

How snakes hunt

Snakes attack with a fast lunge and a single bite. Their jaws and teeth aren't strong enough to take bites out of their quarry so they must swallow everything whole. Small, non-venomous snakes will strike for the head of a mouse or frog and either try to crush its skull or asphyxiate it by engulfing its mouth and nose.

Venomous species will strike and withdraw to avoid injury while the venom takes effect. Boas and pythons use their muscled bodies to constrict. This doesn't kill by crushing; the coils slide past each other so that the scales act as a ratchet. As the victim struggles, they can only tighten further. Sometimes the prey will die of asphyxiation, other times the pressure in the chest cavity becomes so immense that their heart simply stops.

Snakes don't actually dislocate their jaws to swallow large prey, but the lower jaw is very flexible and has some extra joints at the back of the skull to allow it to 'hinge' open extra wide. The left and right halves of the lower jaw aren't joined and so can 'walk' down an animal, drawing it into the serpent's mouth as they go.

THE STATS SUPER SERPENTS

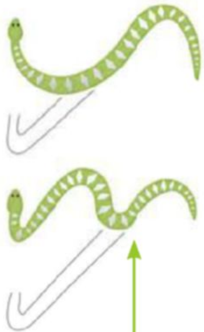
LARGEST PREHISTORIC 15m	MOST DEADLY **Indian Cobra**	LARGEST PREY Capybara
LARGEST VICTIM **Elephant**	VENOM DOSE 100-400mg	TOP SPEED **19km/h**

DID YOU KNOW? *Even a severed snake head can still bite and will automatically inject the maximum dose of venom!*

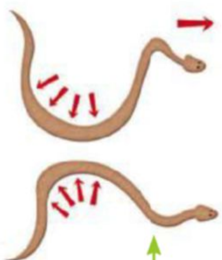
Getting around

With no legs, snakes have developed some clever ways to get from A to B

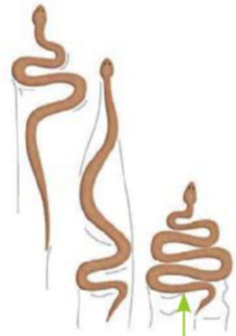
Snakes have many ways of propelling themselves forward, depending on their environment. These use completely different muscle sequences and are much more distinct than, say, the differences between walking and running. All snakes can use lateral undulation but each species has other techniques unique to its habitat. Sea snakes, for example, can use lateral undulation to move backwards, while the chrysopelea snakes of Southeast Asia can even flatten their body into a gliding wing and launch themselves up to 100 metres (328 feet) from one tree branch to another.



Sidewinding
Sidewinding is an adaptation to loose or slippery surfaces, so the contact points between the snake and the ground don't slide backwards. This maximises grip and uses less than one-third of the energy of a lizard which is running the same distance.



Slide pushing
In tunnels, there's no room to move side to side, so the snake alternately braces against the tunnel walls and stretches its body forwards. It's slower than lateral undulation and uses seven times more energy, but it's still faster than rectilinear movement.

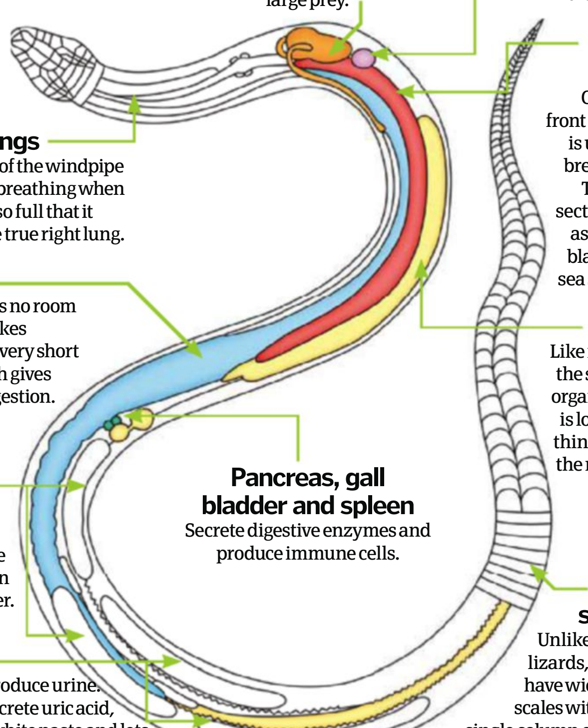


Concertina
The snake pulls its body into a tight series of coils and then braces the tail section as it straightens out again. This needs good grip or something to push against, and it isn't efficient for long distances, but it's a quick way to lunge forward when striking.

Lateral undulation
The most common form of locomotion involves the snake gripping obstructions or small irregularities on the ground with the side of its body, and rippling a wave down their length that slides past the obstruction. Aquatic snakes swim like this by pushing against the water itself.

Rectilinear
The slowest way to move uses the tiny muscles that attach the skin to the ribs. By alternately pulling the skin up off the ground and putting it down again slightly forward, the snake creates a travelling wave that creeps it forward almost silently. This form of movement is employed by pythons and boas when stalking prey.

The anatomy of a snake



Heart
Snakes have no diaphragm, so the heart is free to move out of the way when swallowing large prey.

Left lung
Shrunk to almost nothing to save space, the left lung isn't used for breathing.

Right lung
Only the front portion is used for breathing. The rear section acts as a swim bladder in sea snakes.

Tracheal lungs
This extension of the windpipe allows limited breathing when the stomach is so full that it compresses the true right lung.

Intestine
Because there is no room to coil it up, snakes actually have a very short intestine, which gives them a slow digestion.

Liver
Like most of the snake's organs, this is long and thin to fit in the narrow body.

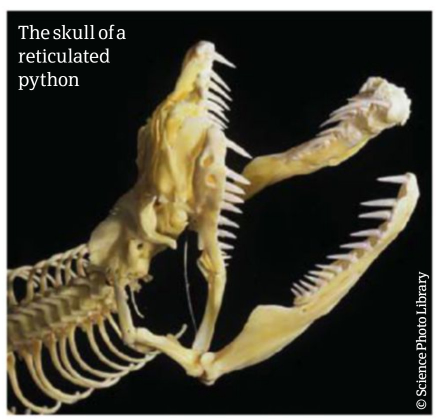
Pancreas, gall bladder and spleen
Secrete digestive enzymes and produce immune cells.

Testes
Where snakes retain paired organs, they are staggered one in front of the other.

Belly scales
Unlike legless lizards, snakes have wide belly scales with just a single column of scales on the underside.

Kidneys
Snakes don't produce urine. Instead they excrete uric acid, which is a dry white paste and lets the snake conserve water.

The snake uses its tongue to smell by bringing air molecules into contact with the Jacobson's organ



The skull of a reticulated python

© Science Photo Library

A deadly cocktail

There are 2,900 species of snake but only a quarter of them are venomous. Out of those, 250 species are deadly enough to kill a human with one bite and around 100,000 people are killed by snakebites worldwide each year.

Snake venom is produced in modified salivary glands and stored in reservoirs behind the eyes. Snakes can choose the dose they deliver with each bite and will sometimes 'dry bite' without injecting at all. Each species has a different venom that is a mixture of hundreds or thousands of different proteins and enzymes. Between them, they can affect every organ system in the body if left unchecked.

MAIN SYMPTOMS

- Rubbery, minty or metallic taste in the mouth
- Fear and panic
- Vomiting
- Diarrhoea
- Dizziness and fainting
- Severe pain
- Blurred vision
- Convulsions
- Rapid, weak pulse
- Spontaneous bleeding
- Numbness
- Breathing difficulty
- Tissue necrosis
- Heart failure

How do penguins survive?

They can endure freezing temperatures, 100mph winds and go without food for months, but what makes these birds so tough?

Known for being a sociable, loyal and really rather tough little creature, the penguin is a resilient member of the flightless bird club. 18 species of penguin can be located throughout the southern hemisphere, ranging from as far south as the coast of Antarctica and as far north as the Galapagos Islands in the Pacific. The smallest species is the appropriately named fairy penguin, which makes its home in the coastal waters of Australia. The biggest member of the family, meanwhile, is the emperor penguin, which lives a somewhat more treacherous life on the perilous frozen continent of Antarctica.

When it comes to breeding, most penguin species (the emperor penguins do things differently; see 'Emperor penguin role reversal' boxout) care for usually one or two eggs in nests built from stones and vegetation. The parents take it in turns to fetch food and protect the eggs for the duration of incubation, which can be anything from 30-60 days. Then, once the chick is born, parents continue to share childcare duties for 2-13 months depending on the species.

Baby penguins won't be going anywhere near the ocean for around six months, or at least until their downy coats have been replaced with insulating, waterproof feathers. The adults therefore have to find and fetch food, which they regurgitate for the chicks. There are three main ways a penguin can bring food back for its young. Because they sometimes have to travel great distances to source fish and crustaceans, the penguin parents have developed a rather nifty way of consuming food out at sea and storing it in their stomachs in special enzymes that prevent it from being digested. Alternatively, they can also partly digest the food into a soft mush. Finally, penguins that have been feeding for weeks can fully digest the food but then secrete a nutritious oil for their young.

The penguin has a number of different predators, including leopard seals, killer whales, giant petrels, sharks and humans among others. Large scavenger seabirds called skuas will even work in teams to swipe untended eggs and unprotected chicks in the blink of an eye. One skua will provide a distraction, luring the adult penguins away from their helpless young, while another strikes, stealing eggs and newborns.

A hungry leopard seal will prowl for penguins at the edge of the ice

The statistics...

Emperor penguin

Type: Bird

Diet: Krill, shrimp and fish

Average life span in the wild: 10-20 years

Weight: Up to 40kg (90lb)

Size: Up to 1.2m (4ft)

Once the chick has hatched, both parents must work tirelessly to rear the young bird

5 TOP FACTS PENGUINS

Bowing
1 When a male and female penguin bow their heads together it is part of an elaborate courting ritual of head movements and calls that helps establish a strong bond.

Born to swim
2 Penguins have a fusiform (torpedo-shaped) body, which helps them tear through the water at high speed. Emperors are thought to be able to reach speeds of 14km/h (9mph).

Safety in numbers
3 As the ocean is teeming with predators, these birds swim in groups – adélie penguins even engage in a spot of synchronised swimming to look like one large creature.

The big moult
4 When a penguin is moulting, it can't go in the water so it may have to fast for up to a month while its feathers grow back. In preparation for this, the bird will eat as much as possible.

Counter-shading
5 A penguin's colouring is useful for both hunting and avoiding predators when at sea. The black dorsal side blends in with the dark ocean depths, while the white belly blends with the sky.

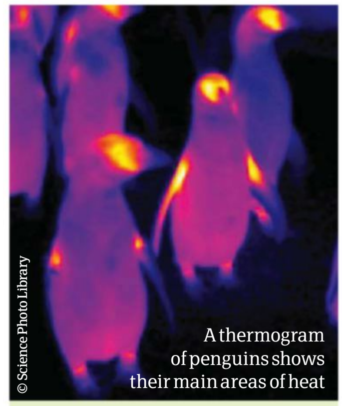
DID YOU KNOW? *Penguins can sleep lying down or standing up with their head or beak tucked under a wing*


A male emperor penguin incubates its egg, shielding it from the worst of the cold

Emperor penguin role reversal

Emperor penguins, native to the barren plains of Antarctica, must endure some of the planet's most extreme conditions on a continent known for its freezing temperatures and relentless high winds. So how do these hardcore birds breed in such bleak conditions? Well, emperors do things a bit differently.

The female will lay a single egg in early winter and instead of taking it in turns to look after the egg, like other penguins, the male emperor stays behind to incubate it while the female heads out across the ice for two months to find food. Huddling is essential for these penguins in order to overcome the elements. Once the emperor chick is born the huddling continues in the form of crèches – not only to keep warm but also as protection against predators. The babies come together in a large group with the adults around the edge.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A thermogram of penguins shows their main areas of heat

Penguin central heating

Penguins are endothermic, which means, along with all other birds and mammals, they are warm-blooded. They regulate their temperature to both conserve energy and avoid freezing in a number of clever ways.

Penguin feathers are very numerous and very tightly packed, making them a bit like fur. At the base of each individual feather is lots of downy fluff, which is great for trapping insulating air close to the penguin's thick skin. Not only that, but penguin feathers are also coated in a special waterproof oil produced in a gland near the tail. Their thick skin has an extra layer of fat or blubber where energy is stored too. And penguins also work together to stay warm. Tens of thousands of penguins will huddle together as one huge colony in order to conserve their body heat, taking it in turns to shelter in the middle.

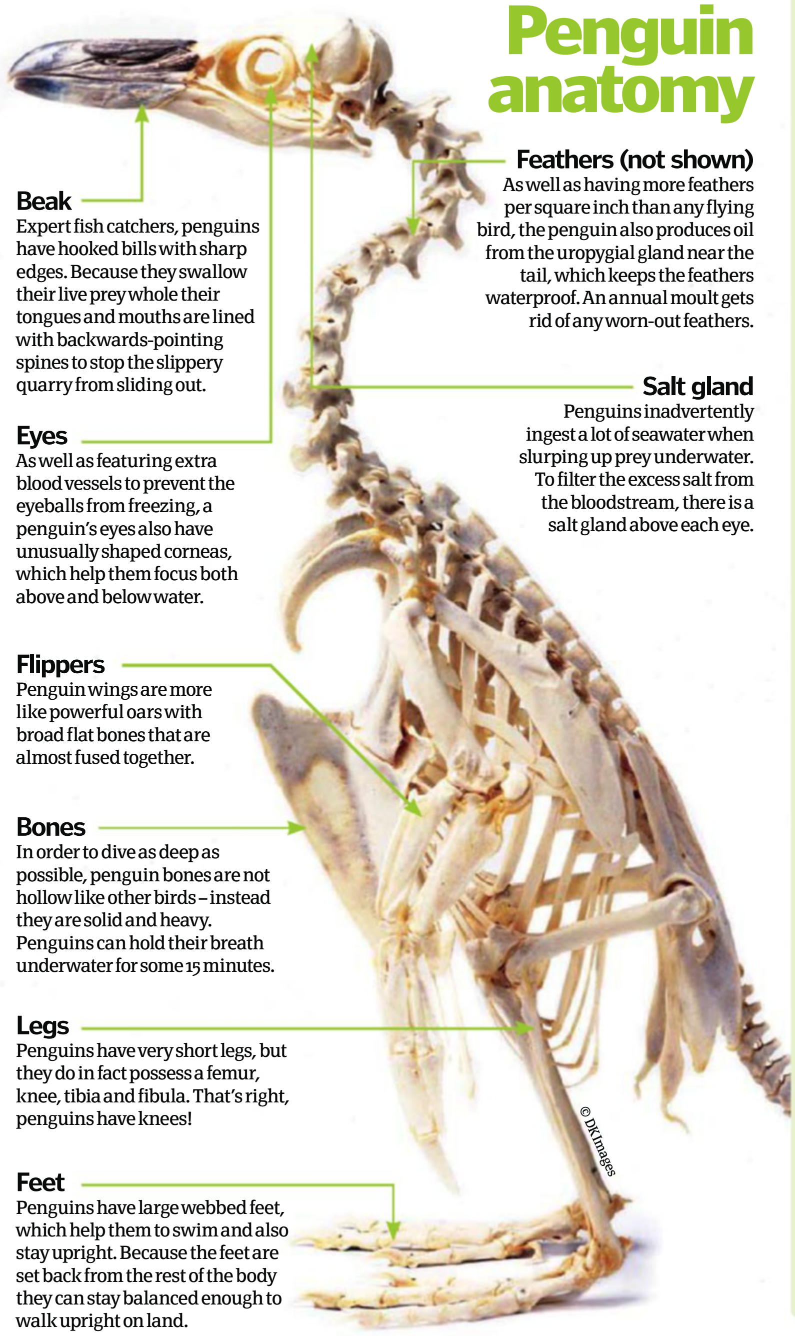
The penguin's circulatory system is also pretty neat. They can adjust the amount of body heat they conserve and release. To stay warm, heat from blood flowing to the feet is transferred to the blood returning to the heart, which explains why penguins' feet don't freeze. Conversely, to cool down, blood vessels in the skin can dilate, moving heat to the surface where it can be released.


© SPL

Do the locomotion

Penguins prefer swimming over flying, which is just as well because unlike airborne birds whose bones are hollow, penguins have dense skeletons; great for diving but not flying. Slick and streamlined in the water they may be, but when getting around on land penguins are undeniably inelegant. They traipse across land on foot using a unique combination of an awkward side-to-side waddle and a two-footed jump for navigating rocks and uneven surfaces. Antarctic penguins are known to travel up to 80 kilometres (50 miles) in search of food. Despite their short legs, they can scurry quite quickly. However, to save energy, penguins have a third method of travel: whenever the opportunity arises they will slide downhill on their bellies, using their wings to steer and their feet to propel themselves. This is known as tobogganing.

Penguin anatomy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Beak
Expert fish catchers, penguins have hooked bills with sharp edges. Because they swallow their live prey whole their tongues and mouths are lined with backwards-pointing spines to stop the slippery quarry from sliding out.

Eyes
As well as featuring extra blood vessels to prevent the eyeballs from freezing, a penguin's eyes also have unusually shaped corneas, which help them focus both above and below water.

Flippers
Penguin wings are more like powerful oars with broad flat bones that are almost fused together.

Bones
In order to dive as deep as possible, penguin bones are not hollow like other birds – instead they are solid and heavy. Penguins can hold their breath underwater for some 15 minutes.

Legs
Penguins have very short legs, but they do in fact possess a femur, knee, tibia and fibula. That's right, penguins have knees!

Feet
Penguins have large webbed feet, which help them to swim and also stay upright. Because the feet are set back from the rest of the body they can stay balanced enough to walk upright on land.

Feathers (not shown)
As well as having more feathers per square inch than any flying bird, the penguin also produces oil from the uropygial gland near the tail, which keeps the feathers waterproof. An annual moult gets rid of any worn-out feathers.

Salt gland
Penguins inadvertently ingest a lot of seawater when slurping up prey underwater. To filter the excess salt from the bloodstream, there is a salt gland above each eye.

Fruit versus veg

Which features distinguish fruit from vegetables?

We think of fruit as sweet tasting and vegetables as more savoury in flavour. However, the difference is far more scientific than how they taste, and in fact depends on the part of the plant being eaten.

Most plants grow from seeds, which develop inside the female part of the plant, known as the ovary. Once matured, most ovaries develop into fruit, which protects the seeds and promotes dispersal. Fruits are the part of a plant that contains the seeds, and include the likes of melons, oranges and even tomatoes and peppers.

Fruits can be dry or fleshy. Peapods are dry fruits that contain the seeds (peas) inside a casing (pod) for dispersal. Fleshy fruits, also known as drupes, include peaches and raspberries. Drupes are often brightly coloured to attract animals and help spread seeds. Peaches come from a single ovary and feature a seed protected within a hard stone, surrounded by fleshy skin. Despite its name, a raspberry is not a berry at all. While berries are defined as fruit with the seeds and pulp produced from a single ovary, a raspberry is the product of many ovaries, or drupes, clumped together – these are known as drupelets.

The word vegetable is a non-scientific term used to define all the other edible parts of a plant. The other parts that can be eaten include leaves (eg spinach), flowers (eg broccoli), stems (eg celery), roots (eg carrots), tubers (eg potatoes) and bulbs (eg garlic). Of course not all parts of all plants can be eaten as some are poisonous.

Fruit or vegetable?

After an encounter with the spray, the odour can be neutralised via a process called oxidation, which breaks down the thiols into compounds that don't smell

Why does a skunk smell?

Famous for its funky odour, how does this animal's key defensive weapon work?

Despite its small size, the skunk can expertly defend itself against predators, such as bears, that are much larger than itself. There are few things that will deter a predator more than an offensive odour, and the skunk, a small mammal native to North America, is probably most notorious for this ability.

Beneath the skunk's tail are two internal walnut-sized glands that produce a foul-smelling oily spray that can be ejected up to three metres (ten feet). The pungent substance is a thiol, a strong-smelling organic sulphur compound, contact with which can result in a burning or stinging sensation in its victims. While this is not particularly damaging, it is the horrendous stench that is most offputting – it sends out a message to would-be predators that this creature doesn't taste good, so stay away.

Skunks will only release their spray if they feel really threatened, because the glands only hold enough of the pungent concoction for five or six strikes and it can take up to ten days to replenish. The animal gives plenty of warning before letting off a stink bomb, including stamping its feet and thrusting its tail high in the air in preparation. When ready to spray, the skunk lifts its tail and extends a tiny protrusion from each gland from which the noxious scent is emitted. Muscles around the glands enable the spray to be projected quickly and with high precision.

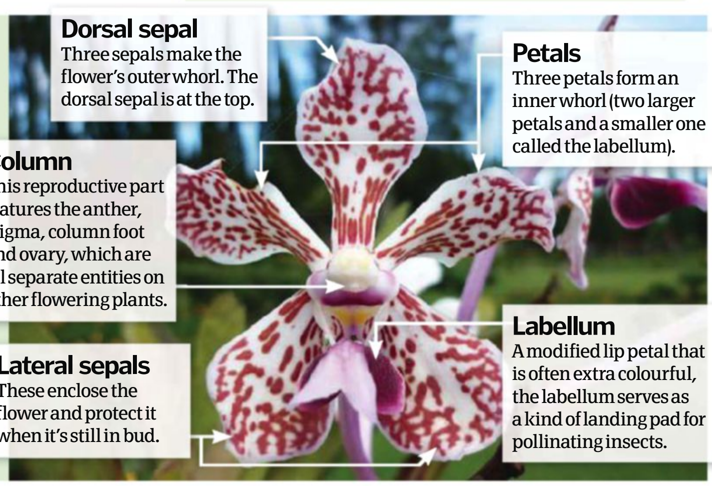
What are orchids?

Discover why they're unlike other flowers

With 25,000 species, the orchid is the largest of the planet's plant families with the most diverse species growing in the tropics and subtropics.

Orchids are found on all continents except for Antarctica and are able to survive pretty much anywhere except true deserts and open water. Orchids grow on the ground using subterranean roots, however, some have also developed the ability to grow up trees and other structures using aerial roots.

What sets an orchid apart from most flowering plants, however, is its reproductive anatomy. Orchids have three petals (including one colourful lower petal called the labellum) and three sepals. While on other plants male and female reproductive organs remain separate, on an orchid these parts are fused in a central column.



DID YOU KNOW?

Where did the ladybird get its name?

During the Middle Ages, European farmers appealed to the Virgin Mary for help with the insects that were decimating their crops. They called the beetles that saved their plants 'Our Lady's Birds', which was eventually shortened to ladybirds. Their red colour was believed to symbolise the virgin's cloak.

DID YOU KNOW? One ladybird can eat over 5,000 aphids in its lifetime

Ladybirds explained

The red-caped heroes of the insect world, ladybirds save the day for gardeners and farmers everywhere

Coccinellids, more commonly known as ladybirds, or ladybugs in North America, are members of the beetle family. There are more than four and a half thousand different species of ladybirds throughout the world living in warm and temperate regions. Though they vary widely in size and colouration, most of us know them as small red beetles with distinctive black spots, a friend of farmers and gardeners.

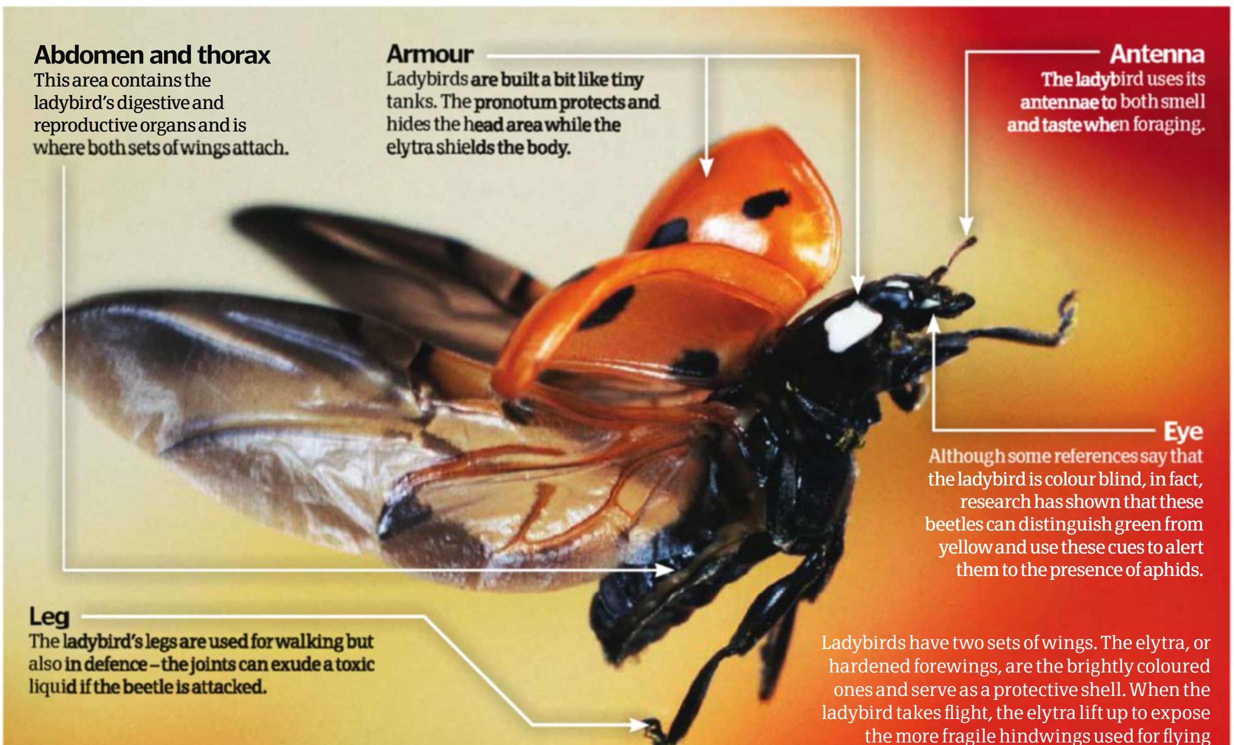
Like all beetles, ladybirds go through a huge metamorphosis on their way to adulthood. Ladybird eggs hatch into larvae, which oddly look a bit like tiny black-and-yellow alligators. These larvae grow and moult, going through several instars, or developmental phases, over a period of two to three weeks, before pupating into adults.

Ladybirds feature aposematic or 'warning' colouration that gives potential predators advanced warning of their bad taste, and when threatened, they can exude a toxic and foul-smelling alkaloid liquid from their joints. In spite of their excellent defence system, ladybirds are not without enemies; parasitic wasps and flies occasionally attack them and some ladybirds fall victim to intrepid spiders and toads too.

Many native ladybird species are under threat from another ladybird species – the Asian or harlequin ladybird (harmonia axyridis). These invaders are generalist feeders and can out-compete resident ladybirds in their native range. They're also somewhat infamous for attempting to hibernate inside human dwellings where they may swarm, stain fabric and even cause allergic reactions.

Currently one-fifth of indigenous British ladybird species are on the decline. In addition to competition with the aforementioned Asian ladybird, climate change and altered land use patterns are likely contributors.

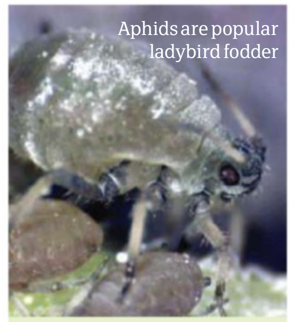
Not all the news is bleak however – a few native ladybirds are expanding their range, and one species – the 13-spot ladybird – previously thought to be extinct has recently been found in Cornwall and Devon.



Ladybirds have two sets of wings. The elytra, or hardened forewings, are the brightly coloured ones and serve as a protective shell. When the ladybird takes flight, the elytra lift up to expose the more fragile hindwings used for flying

Ladybird anatomy

Although we're most familiar with the jaunty appearance of red-and-black ladybirds, these beetles come in many other colours including yellow, orange and blue. The bright colouration and spots for which ladybirds are known serve as a warning to would-be predators to stay away. Contrary to the popular myth, you cannot tell a ladybird's age by its number of spots, nor are spots an infallible way to distinguish between species.



Aphids are popular ladybird fodder

What do ladybirds feed on?

Carnivores and cannibals, ladybirds are justifiably famous (and appreciated) for their habit of eating crop pests. Most ladybird species are carnivorous, consuming soft-bodied insects including aphids, mites, scale insects and white flies. Foraging ladybirds use visual and olfactory clues to home in on food-rich hunting and laying grounds. Newly hatched ladybird larvae have voracious appetites and, if there's insufficient prey available, they may even eat one another! Ladybird mothers also sometimes lay infertile eggs as an additional food source for their young during hard times.

A single ladybird may devour as many as 65 aphids per day. Females consume more than males and both genders eat more when the temperature is warmer, such as in a greenhouse. However, in spite of their reputation, not all ladybird species eat other insects and even the carnivorous species aren't carnivores all the time. Predatory ladybirds rely on pollen, nectar and other plant foods during periods of prey scarcity, and there is a small number of species who spend their lives dining on such delicacies as mildew and fungus.

Mountain formation

ON THE MAP

10 major mountain ranges

1. Ural Mountains
TYPE: Fold mountain range in Russia and Kazakhstan

2. Altai Mountains
TYPE: Fault-block mountain range in Central Asia

3. Tian Shan
TYPE: Fault-block mountain range in Central Asia

4. Sumatra-Java range
TYPE: Discontinuous mountain range system containing active volcanoes, ranging the length of Sumatra (the Barisan Mountains) and Java

5. Serra do Mar
TYPE: Discontinuous mountain range system on east coast of Brazil, fault-block formation

6. Transantarctic Mountains
TYPE: Fault-block mountain chain that serves as a division between East and West Antarctica

7. Eastern Highlands
TYPE: Discontinuous fold mountain range system dominating eastern Australia

8. Himalayas
TYPE: Fold mountain range system in Asia between India and the Tibetan Plateau

9. Rocky Mountains
TYPE: Fold mountain range in western North America

10. Andes
TYPE: Fold mountain range in South America

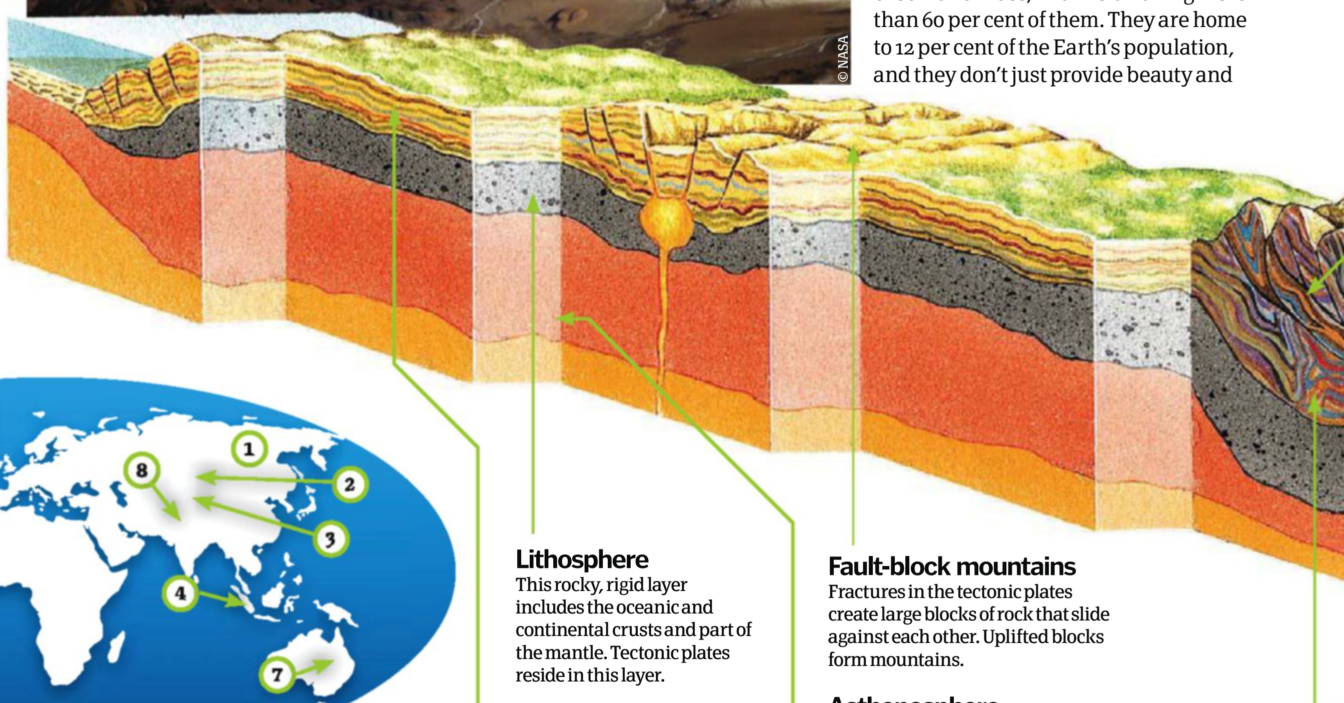

The Himalayas are home to the world's highest peaks

© NASA

How many ways can you make a mountain?

Mountains are massive landforms rising high above the Earth's surface, caused by one or more geological processes: plate tectonics, volcanic activity and/or erosion. Generally they fall into one of five categories – fold, fault-block, dome, volcanic and plateau – although there can be some overlap.

Mountains comprise about 25 per cent of our land mass, with Asia having more than 60 per cent of them. They are home to 12 per cent of the Earth's population, and they don't just provide beauty and



THE STATS MOUNTAIN RANGES

TALLEST: MOUNT EVEREST **8,848m**

SHORTEST: MOUNT WYCHEPROOF (AUSTRALIA) **43m (141ft)**

OLDEST RANGE: BARBERTON GREENSTONE BELT (SA) **3.5bn yrs**

YOUNGEST MOUNTAIN RANGE: HIMALAYAS **60-80m yrs**

DID YOU KNOW? *There is no universal definition of a mountain – for some it means a peak greater than 300m above sea level*

recreation; more than half of the people on Earth rely on the fresh water that flows from the mountains to feed streams and rivers. Mountains are also incredibly biodiverse, with unique layers of ecosystems depending on their elevation and climate.

One of the most amazing things about mountains is that although they look solid and immovable to us, they're always changing. Mountains rising from activity associated with plate tectonics – fold and fault-block – form slowly over millions of years. The plates and rocks that initially interacted to form the mountains continue to move up to 2cm (0.7in) each year, meaning that the mountains grow. The Himalayas, for example, grow about 1cm per year.

The volcanic activity that builds mountains can wax and wane over time. Mount Fuji, the tallest mountain in Japan, has erupted 16 times since 781AD. Mount Pinatubo in the Philippines erupted in the early-Nineties without any prior recorded eruptions, producing the second largest volcanic eruption of the 20th Century. Inactive volcanic mountains – and all other types of mountains, for that matter – are also subject to erosion, earthquakes and other activity that can dramatically alter their appearances as well as the landscape around us. There are even classifications for the different types of mountain peaks that have been affected by glacial periods in Earth's history. The bare, near-vertical mountaintop of the Matterhorn in the Alps, for example, is known as a pyramidal peak, or horn.

Types of mountain

Fold
This most common type of mountain is formed when two tectonic plates smash into each other. The edges buckle and crumble, giving rise to long mountain chains.
Examples: Mount Everest, Aconcagua

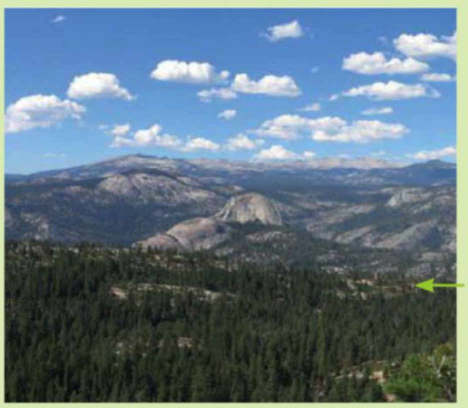
Volcanic
These mountains are created by the buildup of lava, rock, ash and other volcanic matter during a magma eruption.
Examples: Mount Fuji, Mount Kilimanjaro

© Daniel Case

Plateau
Plateau mountains are revealed through erosion of uplifted plateaux. This is known as dissection.
Examples: Catskill Mountains, Blue Mountains

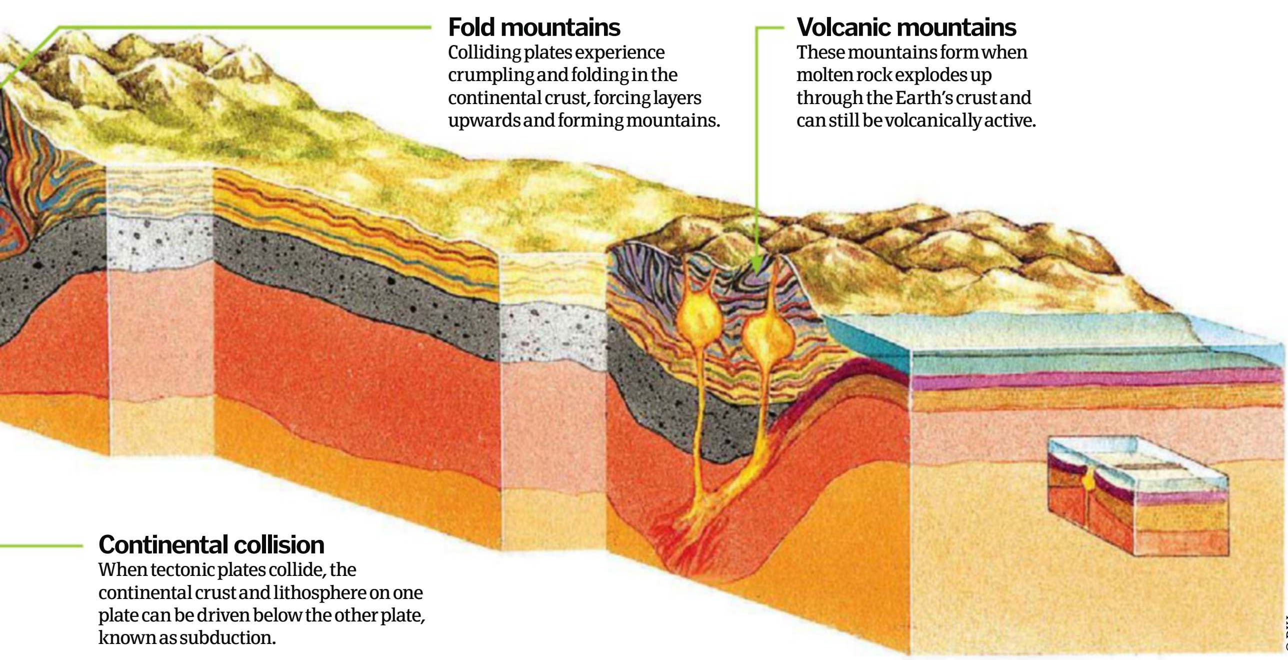
Dome
These types of mountain also form from magma. Unlike with volcanoes, however, there is no eruption; the magma simply pushes up sedimentary layers of the Earth's crust and forms a round dome-shaped mountain.
Examples: Navajo Mountain, Ozark Dome

© NASA



Fault-block
Fault-block mountains form when cracked layers of crust slide against each other along faults in the Earth's crust. They can be lifted, with two steep sides; or lifted, with one gently sloping side and one steep side. **Examples:** Sierra Nevada, Urals

Mountains made from below

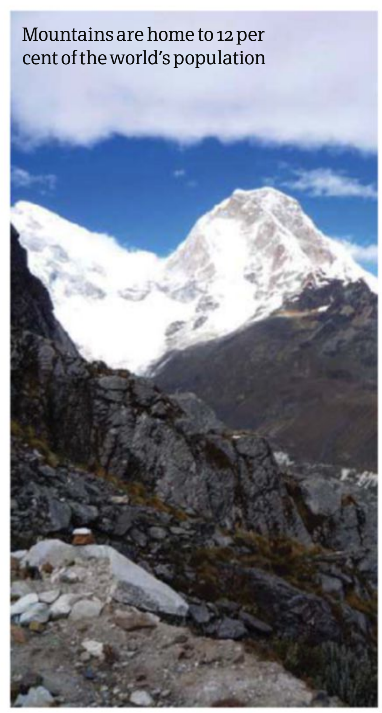


Fold mountains
Colliding plates experience crumpling and folding in the continental crust, forcing layers upwards and forming mountains.

Volcanic mountains
These mountains form when molten rock explodes up through the Earth's crust and can still be volcanically active.

Continental collision
When tectonic plates collide, the continental crust and lithosphere on one plate can be driven below the other plate, known as subduction.

© DK Images



Mountains are home to 12 per cent of the world's population

What are the La Brea Tar Pits?

Discover why California's tar pits are among the richest and most well-known sites for ice age mammal bone excavations

Their preserving nature makes tar pits some of the best fossil museums on the planet

© SPL

The viscous tar lakes known as Rancho La Brea in California have yielded some of the most numerous and insightful fossilised remains ever discovered on Earth. While hundreds of years ago, locals thought the bones excavated from the pits were those of cattle and native wildlife, it now transpires that the remains are in fact those of many million plants, creatures and megafauna dated between 10,000-40,000 years old from the Pleistocene epoch. Specimens discovered include sabre-toothed cats, dire wolves and mammoths.

Millions of years ago, when Los Angeles was underwater, dead marine life and sediments built up on the seabed. As more and more sediment piled up – not to mention the immense weight of the overlying ocean – the layers of carbon-rich organic matter became increasingly compressed and heated. In an environment starved of oxygen this caused the material to become fossil fuels, such as crude oil (petroleum).

Once the sea receded, the tar at La Brea began to form. Petroleum deposits far below the surface were forced to bubble up to the surface by underground pressure. Gradually, as the petroleum evaporated from the surface, large pools of thick, sticky asphalt, or pitch, were left behind.

The land was capable of sustaining vegetation, and plants and even trees took root here, enticing animals and insects to venture out over the pits. This is what led to many prehistoric creatures, large and small, becoming trapped in the sticky lakes.

Once consumed by the tar pits, the bones of the dead animals did not decompose, but instead were perfectly preserved, producing some of the most impressive fossilised remains ever to be found.

ON THE MAP

Tar pits around the globe

1. Tierra de Brea, La Brea, Trinidad and Tobago
2. Lake Bermudez, Estado Sucre, Venezuela
3. La Brea Tar Pits, Los Angeles, USA
4. McKittrick Tar Pits, McKittrick, USA
5. Carpinteria Tar Pits, Carpinteria, USA

What is the wind-chill factor?

Why does this phenomenon make it feel colder than it really is?

The wind-chill factor describes the rate at which your body loses heat due to wind and low temperatures. When it's chilly outside you will of course feel the cold. However, when fast-moving air (ie wind) blows across your exposed skin, you will feel even colder. This is because as wind speed increases, the rate at which heat is carried away from the body also increases, first causing an external temperature drop, then later – and far more dangerously – a reduction in internal body heat.

The NOAA's National Weather Service's windchill index shows the serious implications. For example, if the temperature is -18 degrees Celsius (0 degrees Fahrenheit) and the wind speed is 24 kilometres (15 miles) per hour, the wind-chill factor would be -28 degrees Celsius (-19 degrees Fahrenheit) and human skin would experience frostbite in just 30 minutes.

Worms do a stellar job of revitalising soil, helping plants to grow

How worms burrow

Earthworms are vital as their tunnels aerate the soil while their waste provides it with nutrients

In order to tunnel through soil, an earthworm must be pretty tough despite its soft and delicate outer appearance. The body of the worm is made up of many muscular ring-like segments called annuli, which look like grooves on the outside of the creature's body. It expands and contracts these segments in a wave-like sequence, meaning that different segments contract at different times, to draw itself through the earth.

Additionally, each segment is covered in minuscule thorn-like projections called chaetae, which it uses to grip on to the soil and leaf litter. When a segment contracts it bulges, causing the chaetae to catch on to particles of earth. Once this segment is stuck firmly against the soil, the worm can then extend its other segments to haul itself along.

5 TOP FACTS TOBACCO TRIVIA

Deforestation
1 Wood-cured tobacco is common in South America, which leads to annual deforestation. Brazil alone uses the wood of 60 million trees per year for the curing process.

Pesticides
2 Due to the intense global demand for tobacco, larger and larger crop yields are needed. This is achieved by the application of over 16 different pesticides to the young plants.

Advertising
3 Tobacco advertising is banned across a range of media in the majority of Western countries and, as such, is one of the most highly regulated forms of marketing on the planet.

Bulk
4 In 2010 over 7 million tons of tobacco were produced globally, roughly a 45 per cent increase since 1971. This jump is mainly the result of increased demand in developing countries.

Labour
5 Sadly, child labour is rife within the tobacco industry of developing countries. Further, due to the children's frequent contact with tobacco plants, nicotine poisoning is common.

DID YOU KNOW? No one knows for certain why bees make hexagonal honeycombs, but it's probably to maximise space

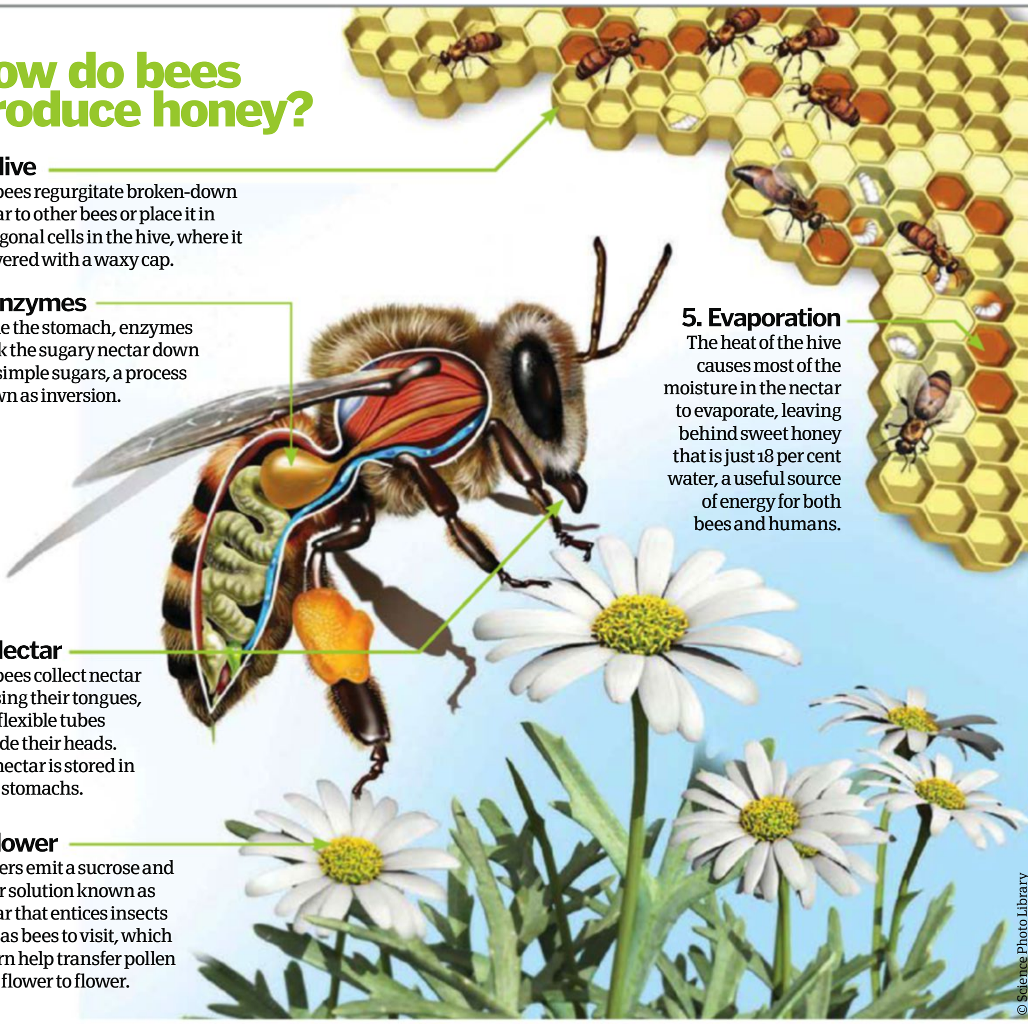
How is honey made?

What makes this sticky substance so popular in the animal kingdom?

In ancient times honey was the primary source of sugar, providing medicinal benefits in addition to the food flavouring that we mostly use it for today. The viscous, dark-gold liquid is produced inside the stomachs of bees from nectar obtained from flowers. It is a hygroscopic liquid, which means that it attracts moisture, a very useful trait for preparing food as it can bind different substances together.

Of course, humans aren't the only beneficiaries of this delicacy, as bees also use it for food, it being an excellent source of sugar and thus energy. Its somewhat acidic quality meant it was once widely used to treat skin problems such as burn marks, although it has been superseded by more effective medicines in modern times.

How do bees produce honey?



4. Hive
The bees regurgitate broken-down nectar to other bees or place it in hexagonal cells in the hive, where it is covered with a waxy cap.

3. Enzymes
Inside the stomach, enzymes break the sugary nectar down into simple sugars, a process known as inversion.

2. Nectar
The bees collect nectar by using their tongues, thin flexible tubes outside their heads. The nectar is stored in their stomachs.

1. Flower
Flowers emit a sucrose and water solution known as nectar that entices insects such as bees to visit, which in turn help transfer pollen from flower to flower.

5. Evaporation
The heat of the hive causes most of the moisture in the nectar to evaporate, leaving behind sweet honey that is just 18 per cent water, a useful source of energy for both bees and humans.

© Science Photo Library

Tobacco explained

From plant to pipe, how is tobacco grown and treated for consumption?

© Henry Kotowski

The colourful, exotic flowers of the tobacco plant, nicotiana tabacum

Loose, dried pipe tobacco

Tobacco comes from the cultivation and then harvesting of plants in the genus nicotiana, of which there are more than 70 species on Earth. It is commonly grown for human consumption either by swallowing, smoking or snuffing.

Tobacco plants are cultivated on an industrial scale by sowing seeds in cold frames/hot beds for initial growth – where they are treated with a number of pesticides to increase chances of survival – and then moved to open fields for continued growth. The planting is typically automated in large-scale plantations, however hand planting and harvesting is still common in developing countries.

Harvesting is undertaken on an annual basis, where the leaves of the plant are systematically removed from the stem; importantly, when the tobacco plants develop their distinctive pink flowers, they are removed to prevent the attraction of insects. Further, as the plants' leaves ripen from bottom to top, there are often multiple harvests in any one season.

Once harvested, tobacco leaves need to be cured. This process of slow oxidation and degradation of carotenoids in the leaves' structure produces a number of compounds that grant them a sweet, oily and aromatic flavour, which is desired when consumed. This ageing is achieved in four main ways: air-cured, fire-cured, flue-cured and Sun-cured – each designed to dry the tobacco leaves to a point where they are ready for shredding and packaging.

The sulphur cycle

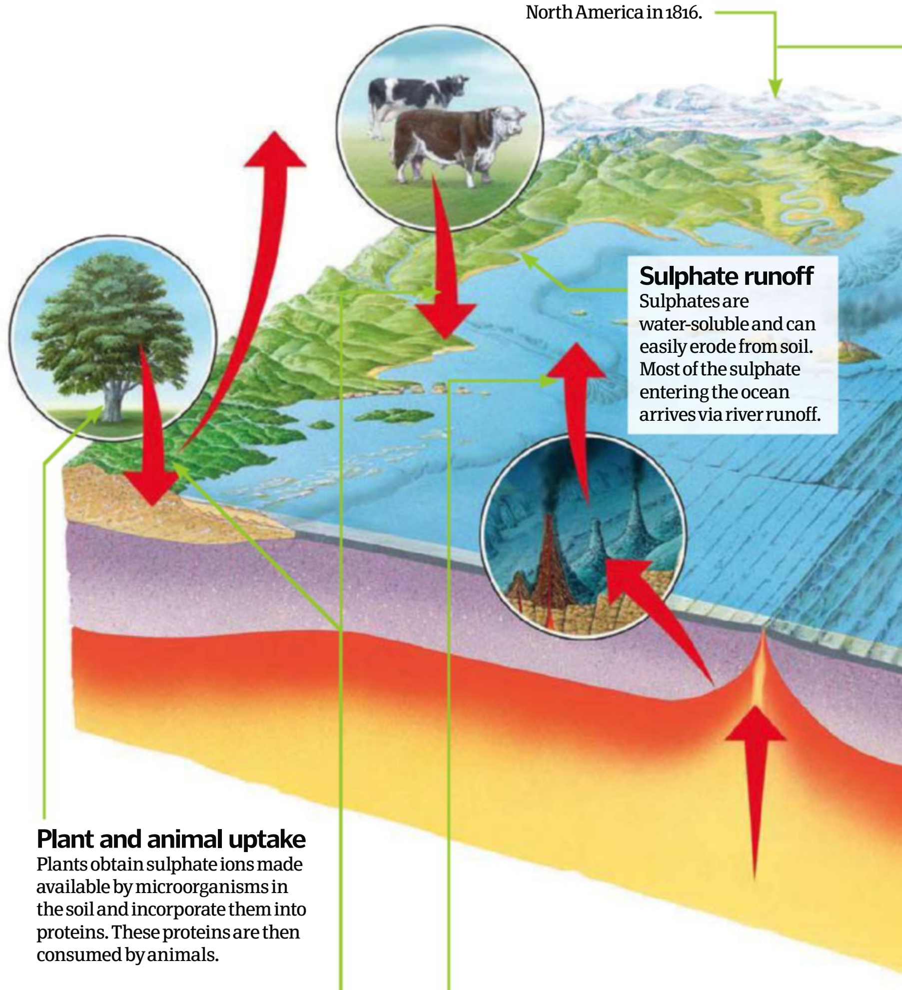
Always mixing and mingling, sulphur is an element that really likes to get around

The sulphur cycle is one of many biochemical processes where a chemical element or compound moves through the biotic and abiotic compartments of the Earth, changing its chemical form along the way. As with both the carbon and nitrogen cycles, sulphur moves between the biosphere, atmosphere, hydrosphere and lithosphere (the rigid outer layer of the Earth). In biology, the water, oxygen, nitrogen, carbon, phosphorus and sulphur cycles are of particular interest because they are integral to the cycle of life.

Sulphur, which is present in the amino acids cysteine and methionine as well as the vitamin thiamine, is a vital part of all organic material. Plants acquire their supply from microorganisms in the soil and water, which convert it into usable organic forms. Animals acquire sulphur by consuming plants and one another. Both plants and animals release sulphur back into the ground and water as they die and are themselves broken down by microorganisms. This part of the cycle can form its own loop in both terrestrial and aquatic environments, as sulphur is consumed by plants and animals and then released again through decomposition.

But this isn't the only iron that sulphur has in the fire. Elemental sulphur is found around volcanoes and geothermal vents, and when volcanoes erupt, massive quantities of sulphur, mostly in the form of sulphur dioxide, can be propelled into the atmosphere. Weathering of rocks and the production of volatile sulphur compounds in the ocean can also both lead to the release of sulphur. Increasingly, atmospheric sulphur is a result of human activity, such as the burning of fossil fuels.

Once in the air, sulphur dioxide reacts with oxygen and water to form sulphate salts and sulphuric acid. These compounds dissolve well in water and may return to Earth's surface via both wet and dry deposition. Of course, not all the sulphur is getting busy; there are also vast reservoirs in the planet's crust as well as in oceanic sediments.



Atmospheric sulphur
Once in the atmosphere some sulphur aerosols can remain for years, reflecting the Sun's energy back into space and lowering surface temperatures many miles away. The eruption of Mount Tambora in Indonesia is thought to have caused the 'year without summer' reported in Europe and North America in 1816.

Sulphate runoff
Sulphates are water-soluble and can easily erode from soil. Most of the sulphate entering the ocean arrives via river runoff.

Plant and animal uptake
Plants obtain sulphate ions made available by microorganisms in the soil and incorporate them into proteins. These proteins are then consumed by animals.

Organic deposition
When biological material breaks down, sulphur is released by microbes in the form of hydrogen sulphide and sulphate salts, as well as organic sulphate esters and sulphonates.

Wet and dry deposition
The airborne deposition of sulphur compounds, whether sulphate salts or sulphuric acid, is the dominant cause of acidification in both terrestrial and coastal ecosystems.

Sulphur and the climate

Human activities like burning fossil fuels and processing metals generate around 90 per cent of the sulphur dioxide in the atmosphere. This sulphur reacts with water to produce sulphuric acid and with other emission products to create sulphur salts. These new compounds fall back to Earth, often in the form of acid rain. This type of acid deposition can have catastrophic effects on natural communities, upsetting the chemical balance of waterways, killing fish and plant life. If particularly concentrated, acid rain can even damage buildings and cause chemical weathering.

However, the environmental impact of sulphur pollution isn't entirely negative; atmospheric sulphur contributes to cloud formation and absorbs ultraviolet light, somewhat offsetting the temperature increases caused by the greenhouse effect. In addition, when acid rain deposits sulphur in bodies of wetlands, the sulphur-consuming bacteria quickly out-compete methane-producing microbes, greatly reducing the methane emissions which comprise about 22 per cent of the human-induced greenhouse effect.

Burning fossil fuels accounts for a large proportion of the sulphur dioxide in the atmosphere

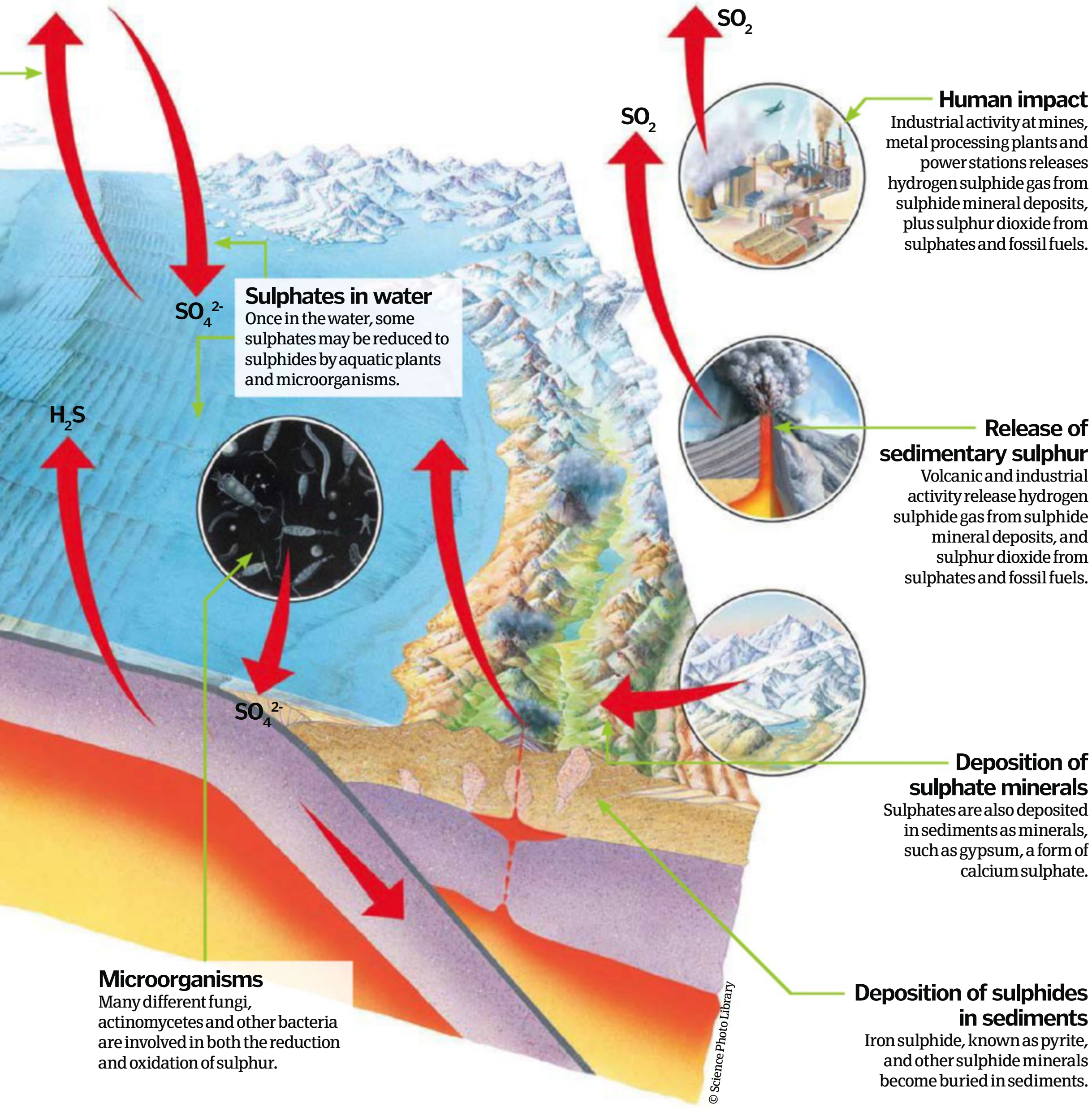
Do you smell something?

Most famous for its stench of rotten eggs, sulphur can really make its presence known. Decomposing organic matter results in the formation of hydrogen sulphide. Not only does it smell terrible but hydrogen sulphide can also be dangerous to aerobic (oxygen-using) organisms as it interferes with respiration.

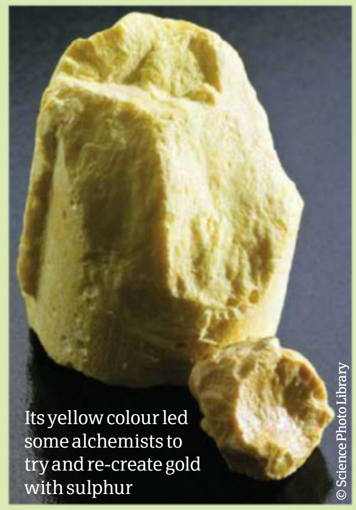
DID YOU KNOW? *Sulphur is actually the 'brimstone' of biblical fame, where it is said to fuel the fires of hell*

The cycle in action

Sulphur is ubiquitous on Earth but much like your average teenager, the behaviour of sulphur depends heavily on its companions. The element is both necessary for all life and potentially highly toxic, depending on the chemical compound. It moves through different compartments of the planet, taking a range of forms, with many and varied impacts.



Large quantities of sulphur in its mineral form are found around volcanoes



Its yellow colour led some alchemists to try and re-create gold with sulphur

What is sulphur?

Sulphur is one of the most important and common elements on Earth. It exists in its pure form as a non-metallic solid and is also found in many organic and inorganic compounds. It can be found throughout the environment, from the soil, air and rocks through to plants and animals.

Because of its bright yellow colour, sulphur was used by early alchemists in their attempts to synthesise gold. That didn't pan out, but people still found many useful applications for it, including making black gunpowder. Today sulphur and sulphur compounds are used in many consumer products such as matches and insecticides. Sulphur is also a common garden additive, bleaching agent and fruit preservative, and is an important industrial chemical in the form of sulphuric acid.

Early users mined elemental sulphur from volcanic deposits, but when the demand for sulphur outstripped supply towards the end of the 19th century, other sources had to be found. Advances in mining techniques enabled the extraction of sulphur from the large salt domes found along the Gulf Coast of the United States. Both volcanic and underground sulphur deposits still contribute to the global supply, but increasingly, industrial sulphur is obtained as a byproduct of natural gas and petroleum refinery processes.

What is lava?

Take a closer look at the molten material ejected by volcanoes

Beneath the Earth flows molten rock known as magma. When a volcano erupts, the resulting explosion shoots this magma out into the atmosphere. At this point the magma becomes known as lava. There is no major difference between magma and lava; the terms merely distinguish whether the molten rock is beneath or above the surface. Caused by gas pressure under the surface of the Earth, a giant volcanic eruption can be incredibly powerful with lava shooting up to 600 metres (2,000 feet) into the air.

Lava can reach temperatures of 700-1,200°C (1,300-2,200°F) and varies in colour from bright orange to brownish red, hottest to coldest, respectively. This viscous liquid can range from the consistency of syrup to extremely stiff, with little or no flow apparent. This is regulated by the amount of silica in the lava, with higher levels of the mineral resulting in a higher viscosity. When lava eventually cools and solidifies it forms igneous rock.

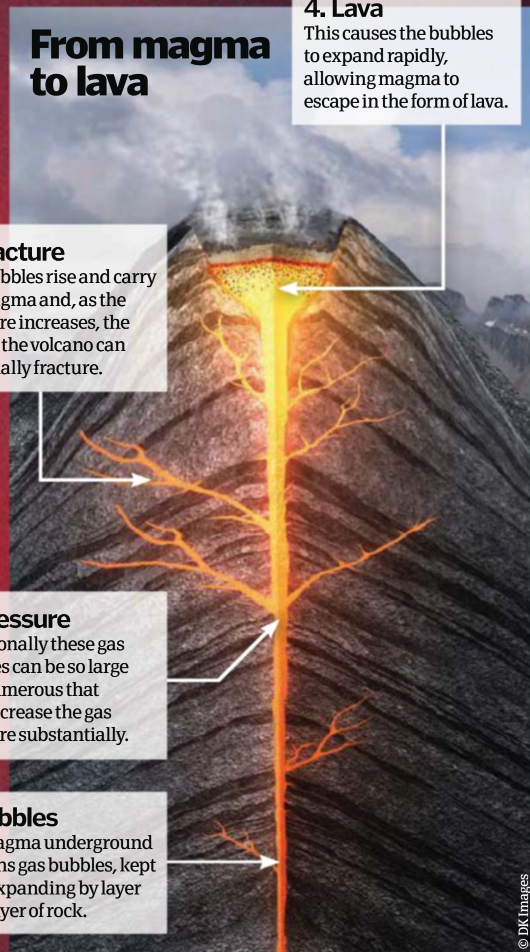
Inside lava are volcanic gases in the form of bubbles, which develop underground inside the magma. When the lava erupts from inside the volcano, it is full of a slush of crystalline minerals (such as olivine). Upon exposure to air the liquid freezes and forms volcanic glass. Different types of lava have different chemical compositions, but most have a high percentage of silicon and oxygen in addition to smaller amounts of elements such as magnesium, calcium and iron.

DID YOU KNOW?

Fighting fire with fire

Explosives have been suggested as a means of stopping lava flows since 1881 and have had varying degrees of success. In 1935 and 1942 the US Air Force was unsuccessful in stopping a lava flow in Hawaii by dropping bombs on it, but the tactic was partially successful in 1975 and 1976.

DID YOU KNOW? *The fastest recorded lava flow is 60km/h (40mph) at a stratovolcano that erupted in DR Congo in 1977*



From magma to lava

4. Lava
This causes the bubbles to expand rapidly, allowing magma to escape in the form of lava.

3. Fracture
The bubbles rise and carry the magma and, as the pressure increases, the rock of the volcano can eventually fracture.

2. Pressure
Occasionally these gas bubbles can be so large and numerous that they increase the gas pressure substantially.

1. Bubbles
The magma underground contains gas bubbles, kept from expanding by layer after layer of rock.

What makes something biodegradable?

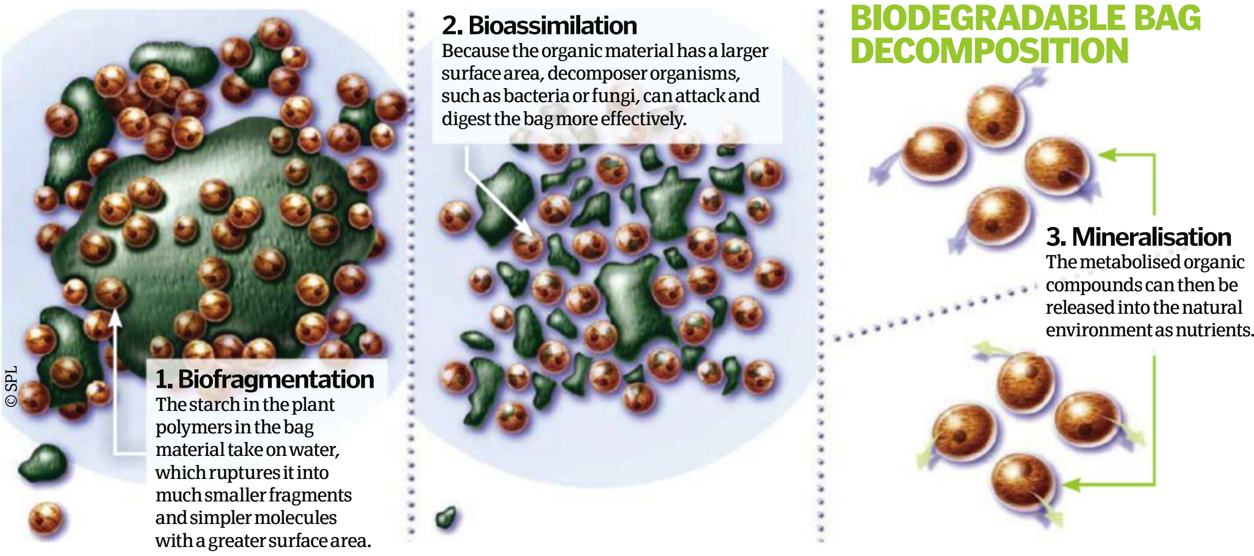
What is microbial decomposition and how does it break down our rubbish?

Did you know that when you throw a soft-drink can in the bin it will take between 200 and 500 years to break down? Plastic dumped in landfill sites gets squashed down and sealed off by tons of earth. While you may think it then just breaks down like organic compost, it actually doesn't because two vital ingredients for biodegradation are missing: oxygen and water. So to stop landfill sites getting bigger and bigger, and to prevent the planet from becoming a floating garbage site, humankind has had to come up with alternative ways to dispose of its waste.

While recycling and reusing products again is one way to limit the amount of trash that we generate, there is also a way to make man-made materials more environmentally friendly: make them biodegradable.

Through the actions of living organisms in the ground, such as algae, bacteria and fungi, the molecular structure of such materials can be metabolised (that is, broken down) into smaller, simpler substances that decompose far more readily.

Traditional plastic is hard to break down as it comprises long, tightly bonded polymers. Plant polymers metabolise easily though. Starch from plants like wheat can be processed to make biodegradable plastic bags. Upon disposal, the grains of starch take on water and expand, breaking the material into tiny pieces that are more easily decomposed.



TIME TO BIODEGRADE

- **Banana:** 3-5 weeks
- **Cardboard box:** 4 weeks
- **Paper:** 2-5 months
- **Rope:** 3-14 months
- **Cigarette butt:** Up to 10 years
- **Leather:** Up to 50 years
- **Batteries:** 100 years
- **Plastic beer can holder rings:** 450 years (but will not fully biodegrade)
- **Plastic bag:** Up to 500 years (but will not fully biodegrade)
- **Glass bottle:** Unknown (will break up into fragments but will not biodegrade)

Truffles explained

Why are these edible underground fungi so sought-after?

A rare delicacy in European cuisine, the truffle is an underground mushroom, hard to find and highly prized. Because they do not contain chlorophyll for photosynthesis, truffles can't survive on their own and so form mycorrhizal (symbiotic) relationships with other plants, trees and bushes in the environment. The two plants will share nutrients between their root systems. If you look hard enough truffles can be found about 30 centimetres (one foot) underground near the roots of pine, oak, chestnut and willow trees in calcium-rich alkaline soils. Inside the truffle is a pulp made of thousands of spores whose differing appearances can be used to classify the species.

Due to their distinctive scent, it is possible for a ripe truffle to be sniffed out by trained dogs. Female pigs were once used to uncover truffles – they could locate the fungi due to its pungent aroma being reminiscent of the smell of a male pig – but when the sows came across a truffle it was difficult to stop them from wolfing it down!

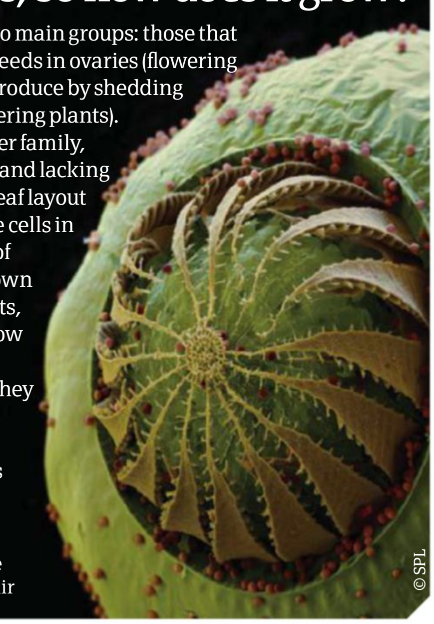

The truffle's Latin name translates roughly as the 'food of kings'

What is moss?

This plant has no traditional roots, stem or leaves, so how does it grow?

Plants are divided into two main groups: those that reproduce by producing seeds in ovaries (flowering plants) and those that reproduce by shedding spores or seeds (non-flowering plants).

Mosses fall into the latter family, growing in damp regions and lacking the usual root, stem and leaf layout of flowering plants. All the cells in a moss plant are capable of photosynthesising their own food thanks to chloroplasts, which means they can grow in a range of locations. As mosses don't have roots, they can attach themselves to rocks and many other surfaces by thin filaments called rhizoids.


Like ferns, mosses reproduce by releasing spores into the air

© SPL

5 TOP FACTS POISON IVY FACTS

Humans are irritated
1 The vast majority of humans (approximately 90 per cent) are sensitive to the urushiol irritant that is present in poison ivy. However, most animals are not affected by the toxin.

Indirect contamination
2 You can be indirectly contaminated by poison ivy as its toxic sap is easily transferred by animals, clothing or even gardening equipment like secateurs.

Do not burn
3 If you have poison ivy in your garden, do not burn it as the urushiol oil can become airborne in the smoke and cause damage to the nose, mouth, throat and even lungs.

Sensitivity threshold
4 Everyone has different sensitivity to poison ivy and so the time it takes for the allergic reaction to kick in and the severity of the symptoms will vary from person to person.

Histamines
5 The body's antibodies become sensitised to the urushiol in poison ivy so if contact is made a second time the immune system releases histamines that cause inflammation.

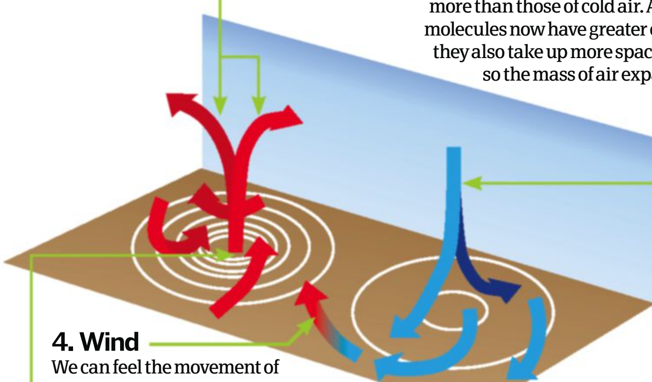
DID YOU KNOW? When a dying leaf falls off a tree a healing layer forms over its point of contact with the stem

The science of wind

It's invisible but we see and feel its effects every day, so just what is wind?

Winds are the air currents in Earth's atmosphere that move due to changes in pressure. When the Sun's energy heats the surface of the Earth, the air mass overhead becomes warmer and less dense, which causes it to expand and rise. Air masses typically cover millions of square kilometres. Because there is now less air pressing down on the Earth, an area of low pressure develops. To maintain balance, the nearest mass of cooler, higher-pressure air automatically moves into the lower-pressure area to fill the gap. The movement of this air mass is wind. The greater the difference in air mass temperature, the more intense the wind blows. Remember, air always flows from an area of high pressure to an area of low pressure.

Low- and high-pressure zones



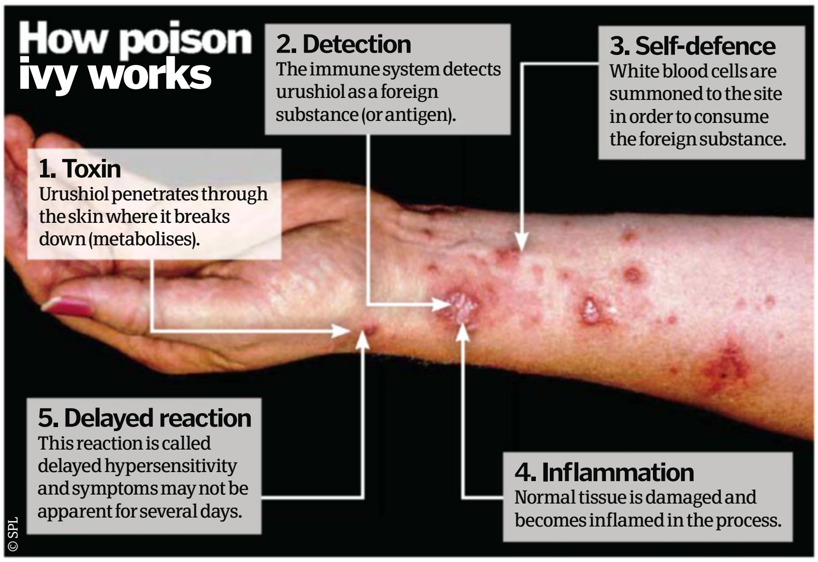
1. Warm air rises
Warm air molecules move around more than those of cold air. As the molecules now have greater orbits they also take up more space and so the mass of air expands.

4. Wind
We can feel the movement of this cold air sinking beneath the rising warm air as wind.

2. Low pressure forms
Because there is now less air pressing down on the Earth, an area of low pressure occurs.

3. Cold air replaces warm air
A colder air mass moves into the space that the warm air originally occupied.

How poison ivy works



1. Toxin
Urushiol penetrates through the skin where it breaks down (metabolises).

2. Detection
The immune system detects urushiol as a foreign substance (or antigen).

3. Self-defence
White blood cells are summoned to the site in order to consume the foreign substance.

4. Inflammation
Normal tissue is damaged and becomes inflamed in the process.

5. Delayed reaction
This reaction is called delayed hypersensitivity and symptoms may not be apparent for several days.

Why is poison ivy so irritating?

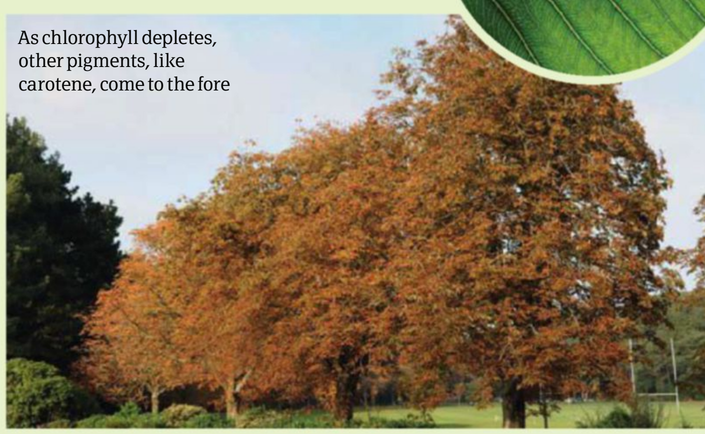
It may look harmless enough but poison ivy is a toxic shrub that grows in most areas of North America

Poison ivy is a plant with leaves that divide into three leaflets and often displays yellow or white berries or small white flowers. The glossy leaves, roots and stem of the plant contain an oily, organic toxin called urushiol, to which nine out of ten people are allergic. If they come into contact with this chemical their bodies overreact, causing a skin irritation known as urushiol-induced contact dermatitis. Thinking it's under attack, the body tells the immune system to take action against the foreign urushiol substance. The resulting allergic (anaphylactic) reaction produces irritation in the form of redness, rashes and itchy skin.

Why do leaves turn red?

The reason that the leaves of deciduous trees go out in a blaze of colour

In temperate and boreal climates each autumn, many trees undertake the process of abscission, the shedding of their leaves. This mechanism is characterised by marked colour changes within the leaves themselves, often turning a variety of colours before falling to the ground. This colour change is caused by the tree ceasing to produce chlorophyll as a response to the colder and darker autumn days. Chlorophyll has a strong green pigment, which despite leaves containing many other chemicals with pigmentation, is dominant to the extent that the entire leaf adopts a green colouration. However, as the chlorophyll breaks down, these other pigments – such as carotene (yellow) and betacyanin (red) – remain, causing the leaf to change colour.



As chlorophyll depletes, other pigments, like carotene, come to the fore

Wolves

They may be the ancestors of man's best friend but these social carnivores are totally equipped for life in the wild

©Science Photo Library

Wolves evolved around 2 million years ago, at the end of the Pliocene epoch. There are 37 subspecies of canis lupus but that includes two that aren't actually wolves. That's because about 16,000 years ago wild wolves were domesticated by man and eventually became canis lupus familiaris, or the dog. In Australia, some dogs escaped to form a feral subspecies – the dingo.

The modern wolf isn't just an undomesticated dog, however. For thousands of years, domestication has acted to change the genetics of the wolf, as well as the dog. Early humans tamed the friendliest and most empathic members of the wild wolf population, so the ones that were left behind were the more suspicious and reclusive individuals. Later, when wolves were hunted because of the threat they posed to humans and livestock, wolves were pushed to ever more remote and forbidding environments and they grew tougher as a result.

Wolf subspecies are divided into the Northern and Southern wolves. The Southern wolves live in the Middle East and South Asia and are lighter, with smaller brains, weaker jaws and shorter fur. The Northern wolves, on the other hand, are adapted to cold climates and live primarily in North America and northern Russia. The largest subspecies is the grey wolf (canis lupus lupus).

Most early studies of wolf social structure were based on captive animals and packs in national parks with artificially abundant food supplies. This led researchers to believe that wolves lived in large packs of 15-30 animals, with an alpha male in charge. The alpha male had priority access to the breeding females and led the hunt. Younger males would try and sneak food and mating opportunities without the alpha male noticing or would gradually work their way up the ranks until they were strong enough to challenge the alpha for the top job. We now know that wolves form much smaller packs in the wild, consisting of close family members and generally hunt in groups

5 TOP FACTS BORN SURVIVORS

Nothing wasted
1 Wolves will eat virtually every part of an animal but they start with the liver, heart and lungs. Then they move on to the muscles, followed by the skin and bone marrow.

Outrunner
2 Wolves can sustain speeds of 40km/h (25mph) for 20 minutes and sprint at up to 61km/h (38mph). One wolf is known to have chased a deer for 21 kilometres (13 miles).

Dry fur
3 Wolf fur does not collect condensation if you breathe on it. This trait means that in cold weather frost is prevented from forming around the muzzle.

Frost resistant
4 Arctic wolves can sleep outside quite comfortably in temperatures as low as -40°C (-40°F). They tuck their muzzles between their rear legs and wrap their tails over their faces.

Lifting power
5 An adult wolf is strong enough to roll a frozen horse or moose by itself. This enables it to get at the underside of the carcass, which may not be frozen solid yet.

DID YOU KNOW? A wolf's stomach can hold 9kg (20lbs) of food. That's the equivalent of 42 Big Macs!

The statistics...

Grey wolf

Type: Mammal

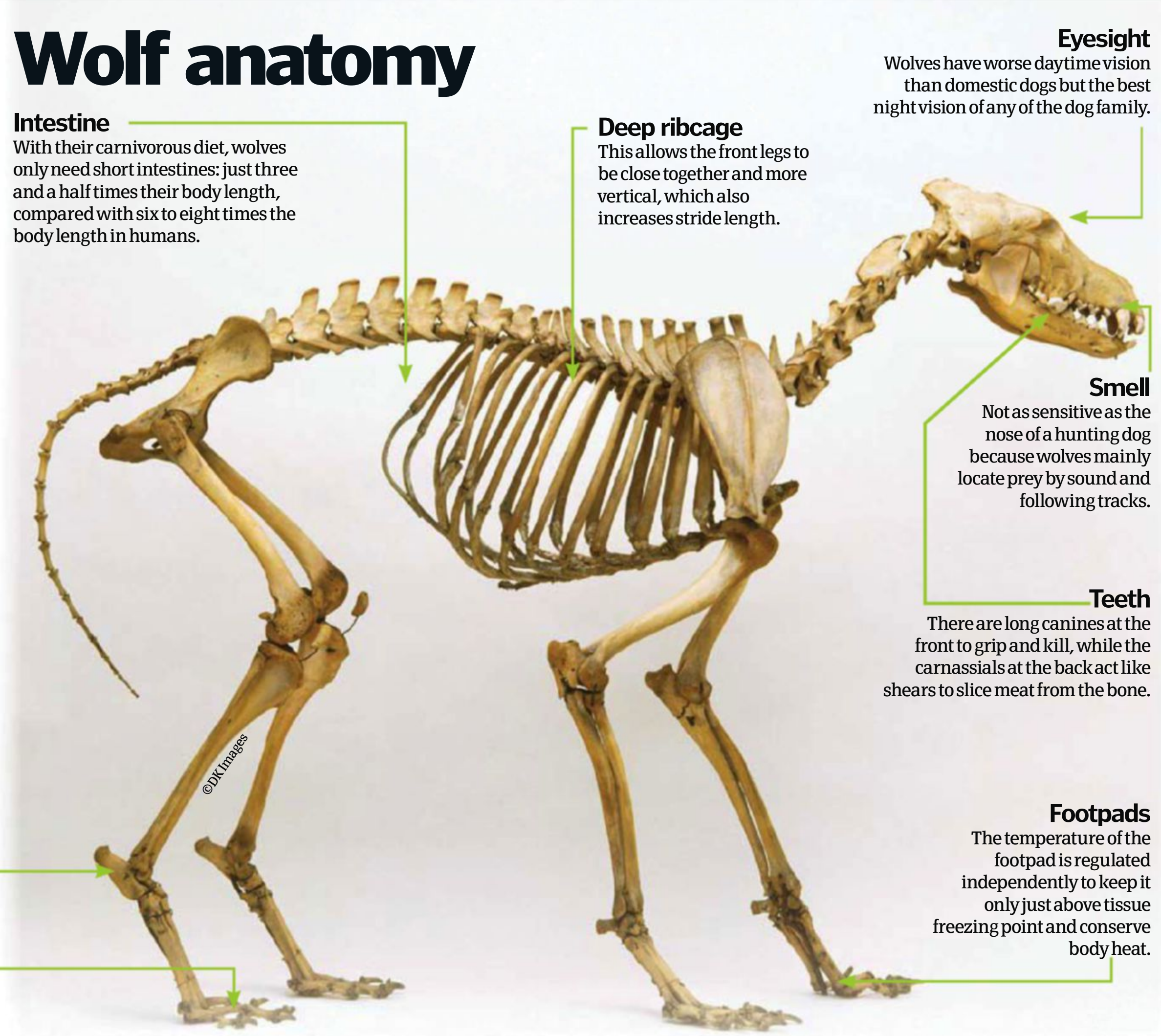
Diet: Carnivore

Average life span in the wild: 8-12 years

Weight: 38kg (84lb)

Height: 85cm (33in) at the shoulder

Wolf anatomy



Intestine
With their carnivorous diet, wolves only need short intestines: just three and a half times their body length, compared with six to eight times the body length in humans.

Deep ribcage
This allows the front legs to be close together and more vertical, which also increases stride length.

Eyesight
Wolves have worse daytime vision than domestic dogs but the best night vision of any of the dog family.

Smell
Not as sensitive as the nose of a hunting dog because wolves mainly locate prey by sound and following tracks.

Teeth
There are long canines at the front to grip and kill, while the carnassials at the back act like shears to slice meat from the bone.

Achilles' heel
The heel extends out a long way to provide extra leverage for the calcaneal, or Achilles', tendon.

Footpads
The temperature of the footpad is regulated independently to keep it only just above tissue freezing point and conserve body heat.

Tippy toes
Wolves are digitigrade, which means they walk on tip-toes. The rest of the foot extends the effective length of the leg and allows longer strides.

of just two to six. This is an adaptation to the harsh conditions they live in because larger packs actually catch less food per individual than smaller ones.

Wolves are opportunistic hunters and will eat a wide range of animals from mice and birds to hares and deer. But when they go after these small and medium-sized prey, they are competing with a lot of other predators, including eagles, lynx and wolverines. Where wolves excel is in hunting the huge elk, bison and caribou. These animals may weigh 10 or 15 times as much as an individual wolf and have horns and a powerful kick to defend themselves. Hunting this kind of quarry is all about escaping injury. The elk is fighting for its life and can afford to put everything it has into the struggle; the wolf, however, is only fighting for its dinner so must be more careful. One well-aimed kick may injure him badly enough that he can't hunt and will starve to death before his wounds heal.

A pack can travel 19-80 kilometres (12-50 miles) in a day, looking for a herd. When they find one, they don't waste time stalking. Instead they will trot straight up and weave in and out among the herd, trying to spook it into running away. A herd of elk or caribou is almost impregnable if it stands its ground but once it starts running, the wolves can run alongside and weigh up which are the weakest individuals. Wolves have no problem at all in keeping up and can bound through deep snow more easily than narrow-hoofed deer. When they pounce, they will strike for the soft tissue of the perineum; their teeth can leave a 15-centimetre (5.9-inch) wound that results in massive blood loss. Three bites can be enough to bring down a healthy adult elk. Another tactic is to jump for the nose – also a soft area that bleeds profusely.

Despite all this, only about one attack in ten results in a kill. And when they


Life in a pack is centred around dominance and submission

are successful, the wolves still have to defend the carcass from various other predators such as bears, coyotes, wolverines and other wolves. Large grizzly bears will often follow wolf packs and wait for them to make a kill, before stealing it. In Siberia, wolves are also directly preyed upon by tigers. Wolves used to be common throughout most of the United States, Europe and Asia but were extirpated from all heavily populated areas by the early 20th century. Southern wolves exist only as isolated, endangered populations but the grey wolf is still common in Canada, Alaska and Russia.

Hungry like the wolf

It's a misconception to think of wolves as pack hunters. While a few large packs of 30 or more individuals have been seen, most are small family groups. Wolves are capable of taking moose and deer on their own or in pairs. A typical wolf pack is a single breeding pair with this year's pups and the youngsters from last year's litter – between 5 and 11 animals all together.

By the age of two, most wolves will move away to start their own pack. This normally isn't long enough to learn complicated cooperative hunting techniques, although some packs will try and drive prey towards an ambush. Generally though, when hunting large prey, wolves will split one animal from the herd and then run it down and attack from behind. The breeding pair will monopolise the kill, before allowing the others to feed.

Holding the pack together

Boundary disputes
Up to 65 per cent of wolf fatalities are caused by other wolves, at the border between two territories.

Active submission
Used as a form of greeting. The submissive wolf approaches and licks the face of the dominant wolf.

Scent marking
Urine and faeces are both used to mark a territory. Markers are placed every 240m (787ft) and renewed after two or three weeks.

Raised hackles
An aggressive wolf holds his body high and raises the long hairs on his shoulders to make his body appear larger.

Howling
Wolves howl to call the pack together or locate each other during storms and as a rallying cry when chasing prey.

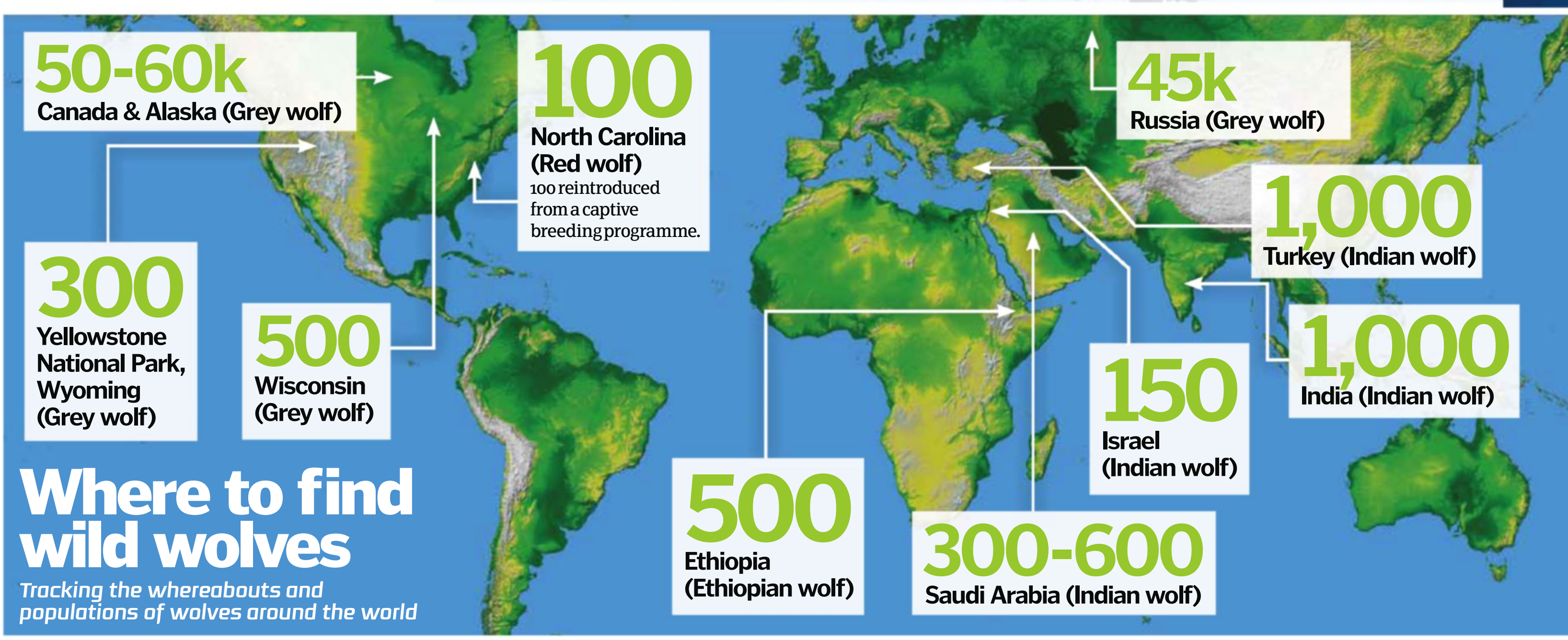
Tail angle
A tail held out straight, or with the base high and a drooping tip, is an aggressive gesture. Hanging low between the legs is submissive.

Flattened ears
Another dominant gesture, used at kill sites to signal ownership of the carcass.

Passive submission
To show submission a wolf rolls onto its back and allows the other wolf to sniff.

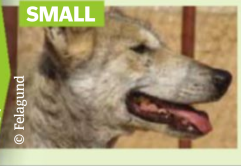
Where to find wild wolves

Tracking the whereabouts and populations of wolves around the world



Head to Head
OTHER SUBSPECIES OF CANIS LUPUS

SMALL


© Felagund

1. Arabian wolf
A variety of wolf that has adapted to life in the desert, it grows to about 66cm (26in) tall. It has short hair in the summer and a longer coat in winter.

BIG


© Glen Fergus

2. Dingo
A little shorter than the Arabian wolf, but more powerfully built. Originally descended from domesticated dogs that escaped into the wild.

BIGGER

3. Domestic dog
Some dog breeds are tiny, but the Irish wolfhound and deerhound are bigger than most subspecies of wolf. Only the grey and tundra wolves are larger.

DID YOU KNOW? *A wolf has a bite that exerts 10MPa pressure (1,500psi) – twice as much as a German shepherd dog*

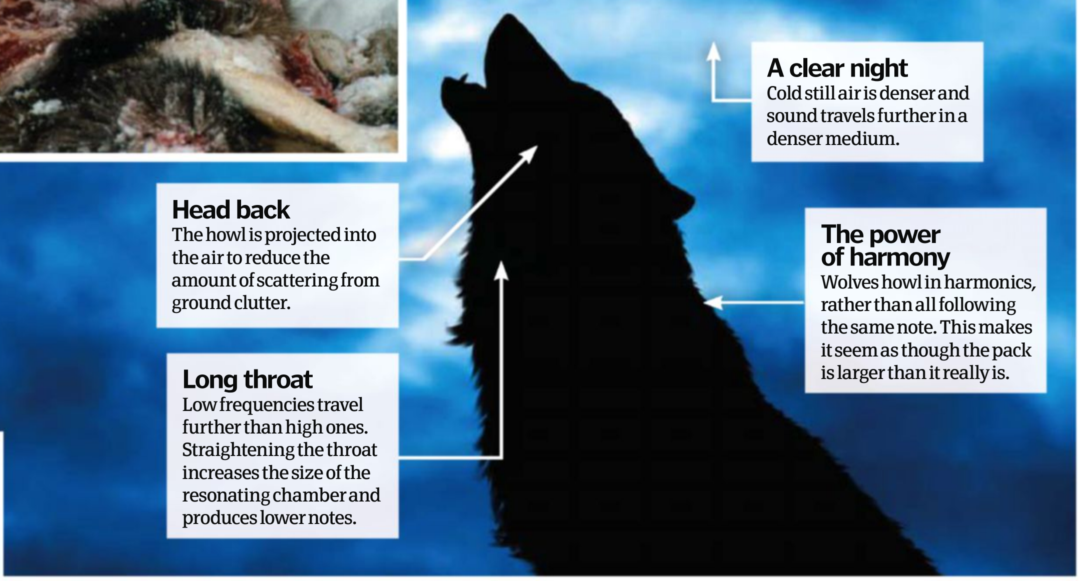
Do wolves really howl at the moon?

No, they don't, they howl at each other. Howling is a long-range signal that allows wolves to reconnect with the pack if they become separated and to warn off rival packs. Howls have a low fundamental frequency of 150-750Hz because low frequencies carry much further, but they also layer this with up to 12 harmonic overtones to exaggerate the number of wolves in a pack. A lone wolf will not risk advertising his presence near the boundary of his territory, but a small group can keep rivals at bay by bluffing that they are more numerous.

As well as howling, wolves will bark as an alarm call, growl and snarl when staking ownership of a kill, and whine when playing or investigating one another.

Canine teeth are used to grip and the carnassials to tear flesh off a carcass

How does a howl travel so far?




©NASA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A wolf's coat comprises two layers: a thick furry undercoat covered by a layer of longer guard hairs


©Shelley Black

INTERVIEW
Shelley Black

Along with her husband, Casey, Shelley has run the Northern Lights Wildlife Wolf Centre in Golden, British Columbia, for ten years. Their aim is to debunk the myths surrounding the wolf and show the critical role that these predators play within an ecosystem

How It Works: What are the major threats that the wolf faces today?
Shelley Black: In Canada it's still legal for a wolf to be hunted, baited and trapped in most areas all year round; these animals are treated like vermin. Beyond the threat of hunting, they're also losing their habitat and food sources to humans [with the expansion of towns and new roads being built, and so on]. In the central Rocky Mountains, in the Banff National Park area, the number one cause of wolf mortality is humans; only five per cent die of natural causes.

HIW: How are groups like yours promoting the conservation of the wolf?
SB: We are promoting wolf conservation by speaking to the public, from all around the world, and insisting that we have to stop eradicating wolves from the forest. We're also going into schools to promote this message. By giving hands-on experiences with wolves I think it gives the public a much better understanding of how misrepresented they are. One of the major points we try and get across is how the wolf is a 'keystone species' [one that plays a vital role in maintaining the structure of an ecosystem], as well as a bio-indicator species.

HIW: Tell us one characteristic that makes the wolf such a remarkable species.
SB: There are far more than one! They are extremely social and intelligent animals; I'd say one of the few species that can outsmart humans. Their endurance and ability to stay alive never ceases to amaze me.

HIW: Generally, what do you find is the public perception of wolves when they first arrive at the Northern Lights Centre?
SB: Most people think they are scary, or they are generally unsure. When they come to the Centre, we inform them that there has never been a proven vicious attack by a healthy non-habituated wolf on a human in the wild. After meeting the wolves themselves, by the time they leave, visitors take away a whole new perspective – which is why we're here.

For more info, see: **www.northernlightswildlife.com**

Elastic energy in the leg muscles transforms into mechanical energy during the leap

How do frogs leap?

Discover what enables this amphibian to jump up to 50 times its own body length

The secret to why frogs can jump so far is in their legs. The ideal way for a frog to evade predators is to leap away in a split second. The amphibians have evolved extremely strong hind legs with specially fused leg bones and proportionally big feet, which are perfect for launching into the air over huge distances, as they enable the frog to push off against the ground for longer.

Using high-speed cameras to examine the anatomy of a frog as it jumps, researchers have discovered the mechanics of how a frog can travel so far. Pre-jump the muscles in a frog's powerful hind legs are lengthened and stretched as they sit in the typical crouching position. Upon takeoff the muscles connecting the pelvis to the knee contract as the frog flies into the air, pulling the upper hind leg backwards and propelling the frog forwards. The muscles then stretch again once the frog has reached the ultimate height of its jump. These super-stretchy muscles store a huge amount of elastic energy, which in turn is transferred into mechanical energy.

The appropriately named rocket frog can jump a massive two metres (6.6 feet) – that's over 50 times its own body length. This is the equivalent of Olympic triple-jumper Jonathan Edwards jumping around 90 metres (295 feet) in one stride – let alone three.

One mighty leap can be the difference between life and death for a frog

READY FOR TAKEOFF...

1. Stretched and ready
In a crouching position, the super-flexible frog leg muscles are stretched like springs and ready for release.

2. Forelegs
The frog flexes its forelegs first to initiate the jump.

3. Hind legs
Simultaneously the hind legs extend to a vertical position and lock straight at the height of the kick. The thighs then swing round to the side and draw the legs back up into a bent position.

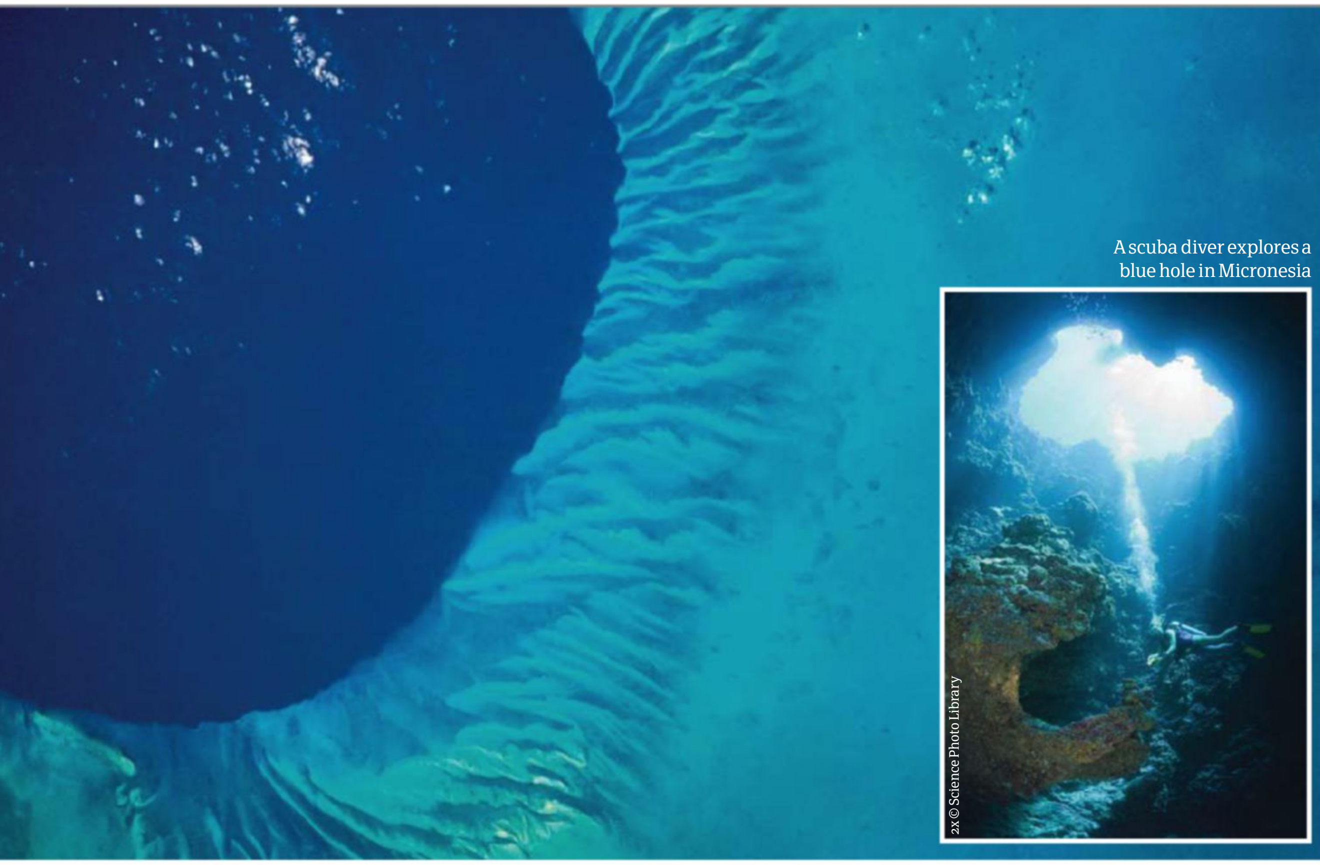

© NASA

DID YOU KNOW?

Alien habitat on Earth

The oxygen-free environment of a blue hole results in some of the rarest conditions on Earth. Groups such as NASA are attracted to blue holes to undertake research into the bacterial lifeforms found within. The findings could be indicative of possible ET life on other planets. The lack of oxygen also helps to preserve things like fossilised sea-creatures.

DID YOU KNOW? *Some 20 divers who embark on blue hole cave explorations die each year*



A scuba diver explores a blue hole in Micronesia

2x © Science Photo Library

How a blue hole forms

Stare into the dark abyss as we explain the creation of these mysterious underwater sinkholes

The most abundant examples of these striking geological phenomena are found in and around the islands of the Bahamas. Some 300,000 years ago, when the ice age caused the ice caps to grow and the sea level to fall by up to 120 metres (394 feet), conditions in the Bahamas were well-suited to the formation of underwater caves known as blue holes. A type of karst formation, the blue hole forms as a result of recently exposed soluble rock – such as the limestone uncovered due to a drop in sea level – being eroded by acidic groundwater and rain, which enters through open faults. This causes cavities, caverns and networks of underground tunnels that weaken the structure of the limestone until it collapses in on itself as a sinkhole. When the sea level rises again the entrance to the cave below the surface of the ocean becomes apparent due to the contrast of the deep dark blue of the sinkhole with the lighter shallows of the tropical oceans surrounding it.

One of the most remarkable examples of a blue hole on Earth is the practically perfect circle of the Great Blue Hole off the coast of Belize; at over 300 metres (1,000 feet) across it's also the world's largest. Underwater sinkholes can be as deep as several hundred metres and, due to their hostile conditions, pose an extremely dangerous challenge to even the most experienced divers.

ON THE MAP

Where in the world can you find blue holes?

1. Bahamas, Atlantic Ocean, Dean's Blue Hole: Deepest
2. Egypt, Red Sea, Blue Hole: Dangerous
3. Belize, Caribbean Sea, Great Blue Hole: Best for diving
4. Guam, Pacific Ocean, Guam Blue Hole: Popular

"Some 300,000 years ago, conditions in the Bahamas were well-suited to the formation of some underwater caves known as blue holes"

Blue hole formation

1. Bahamas
Before the ice age the limestone platforms of the Bahamian islands remain intact.

2. Sea level drops
With the onset of the ice age some 300,000 years ago, the sea level drops – by up to 120m (394ft).

3. Soluble rock exposed
Limestone becomes exposed to the elements, eg rain, which get into any cracks and start to erode the rock.

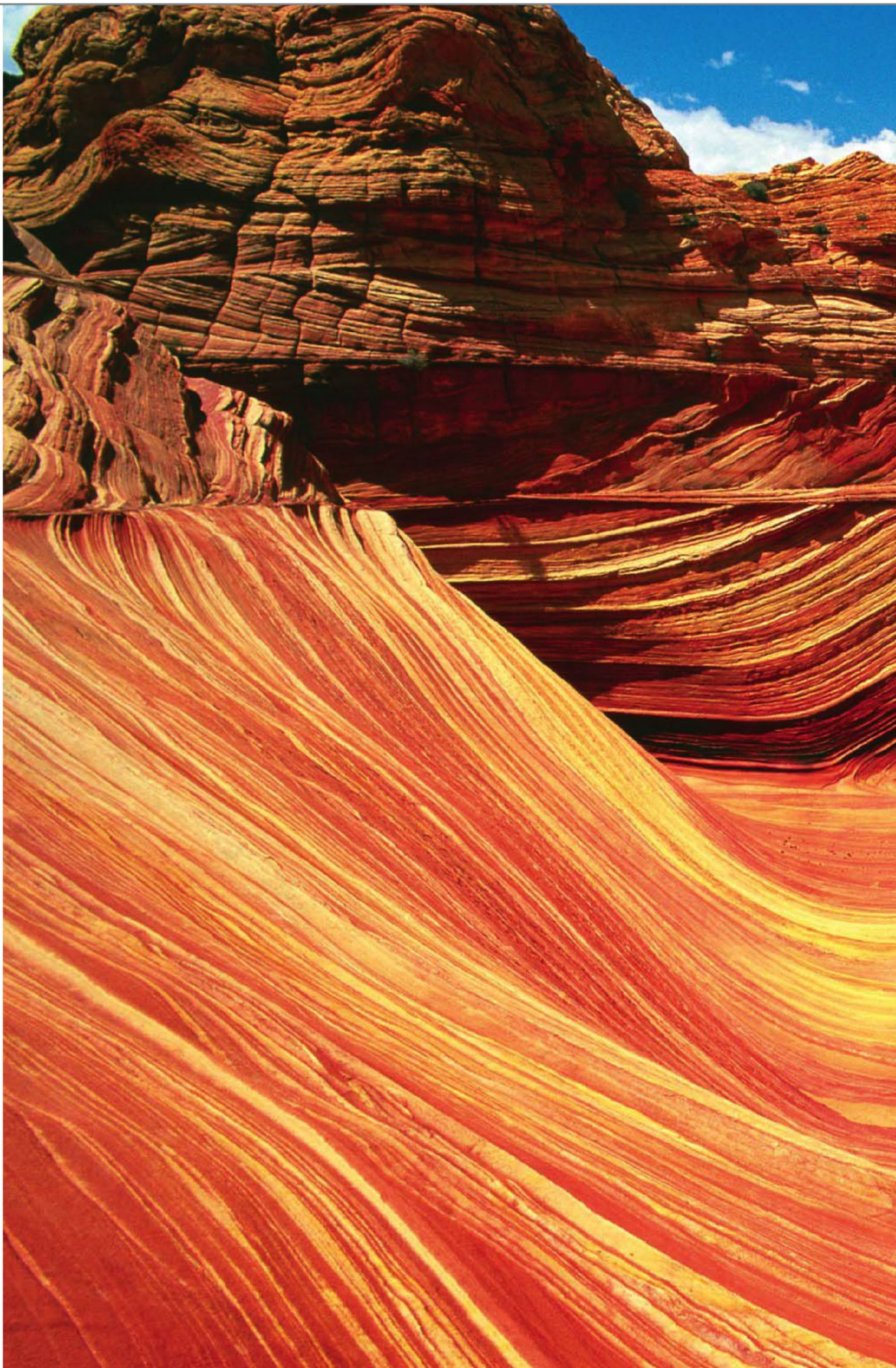
4. Vertical cave forms
Over the course of time the soluble rock is increasingly worn away until eventually a steep, deep-sided vertical cave forms.

5. Sea level rises
With the passing of the ice age, the ice caps begin to melt and sea levels rise once again, refilling the vertical cave with ocean water.

6. Blue hole
A thin layer of less dense freshwater lies over the denser ocean water. If the sea level rises above the height of the opening of the cave an offshore blue hole is visible from above. The dark of the ocean water in the cave is distinct from the shallow coastal waters surrounding it. Inland blue holes are described as those whose entrance is accessible from land.

The Wave

Check out this striking sedimentary rock formation in the USA



The Wave is a remarkable Jurassic Navajo Sandstone rock formation located within the hills of the Utah/Arizona border. The swirling, undulating rainbow of colour was formed from the iron-rich Arizona rocks throughout the last 200 million years.

The sandstone in The Wave is a type of sedimentary rock, consisting of fine fragmented quartz particles that have been worn away and deposited on the riverbed. As more and more layers of sedimentary particles were deposited, the sediment was compacted and bound together by minerals to form the fragile yet strikingly striated rocks that are common to the Coyote Buttes region of the Paria Canyon-Vermilion Cliffs Wilderness area in Arizona.

The multicoloured layers of rock that make up The Wave are known as strata and they were created due to the presence of different rock and sediment types featuring various thicknesses and hardness. While usually the sediment layers form horizontally one on top of the other, contortion of the Earth's crust can cause the rock to twist, fold and buckle into different directions.

The soft, brittle rocks of The Wave are so delicate that the Bureau of Land Management has imposed a limit of just 20 hikers per day who are allowed to venture into the North Coyote Buttes area.

Head to Head
COOL ROCK FORMATIONS

1. Devil's Marbles
Location: Northern Territory, Australia
These giant igneous boulders formed due to chemical weathering.

2. Giant's Causeway
Location: County Antrim, Northern Ireland
Hexagonal rock columns formed when Europe and North America separated.

3. Rock of the Brooding Hen
Location: Quixadá, Brazil
Known locally as 'Pedra da Galinha Choca', this igneous formation resulted from softer surrounding rock wearing away.

DID YOU KNOW? *The Wave in Arizona is not to be confused with a similar Australian rock formation called Wave Rock*

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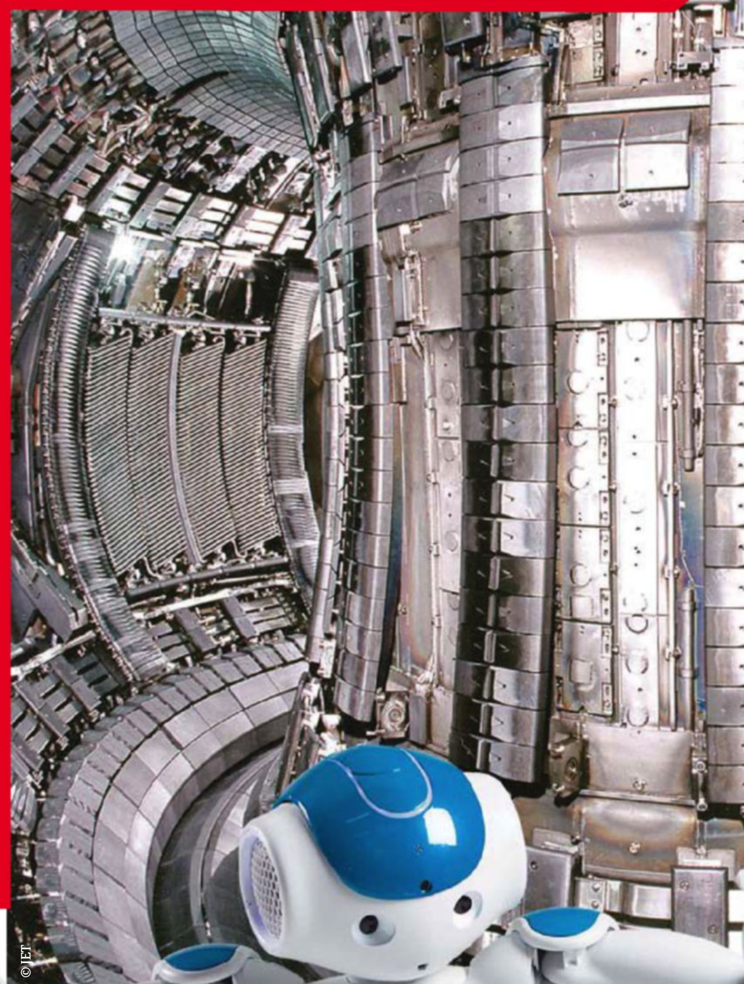
TECHNOLOGY



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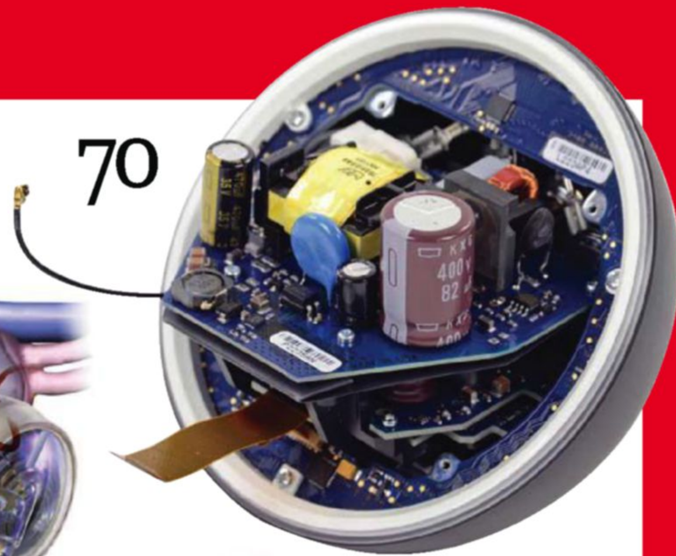

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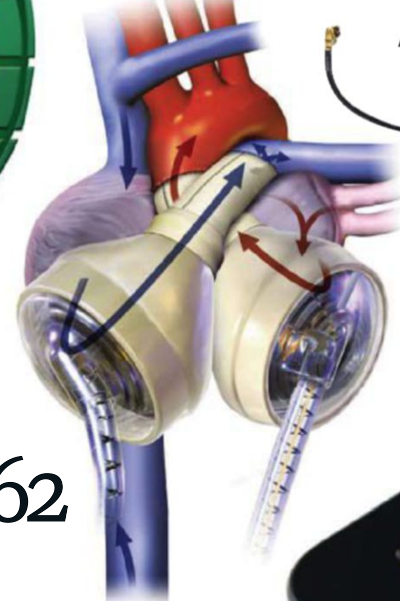

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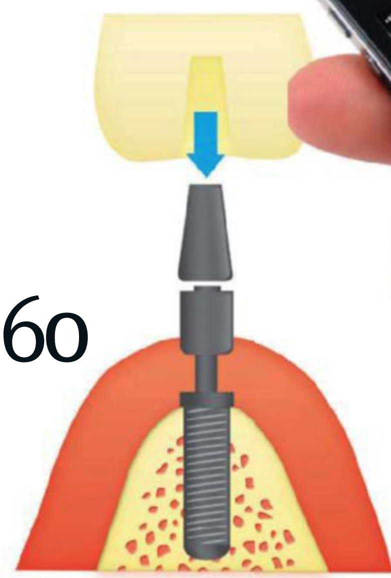

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Nuclear reactors

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Robotics

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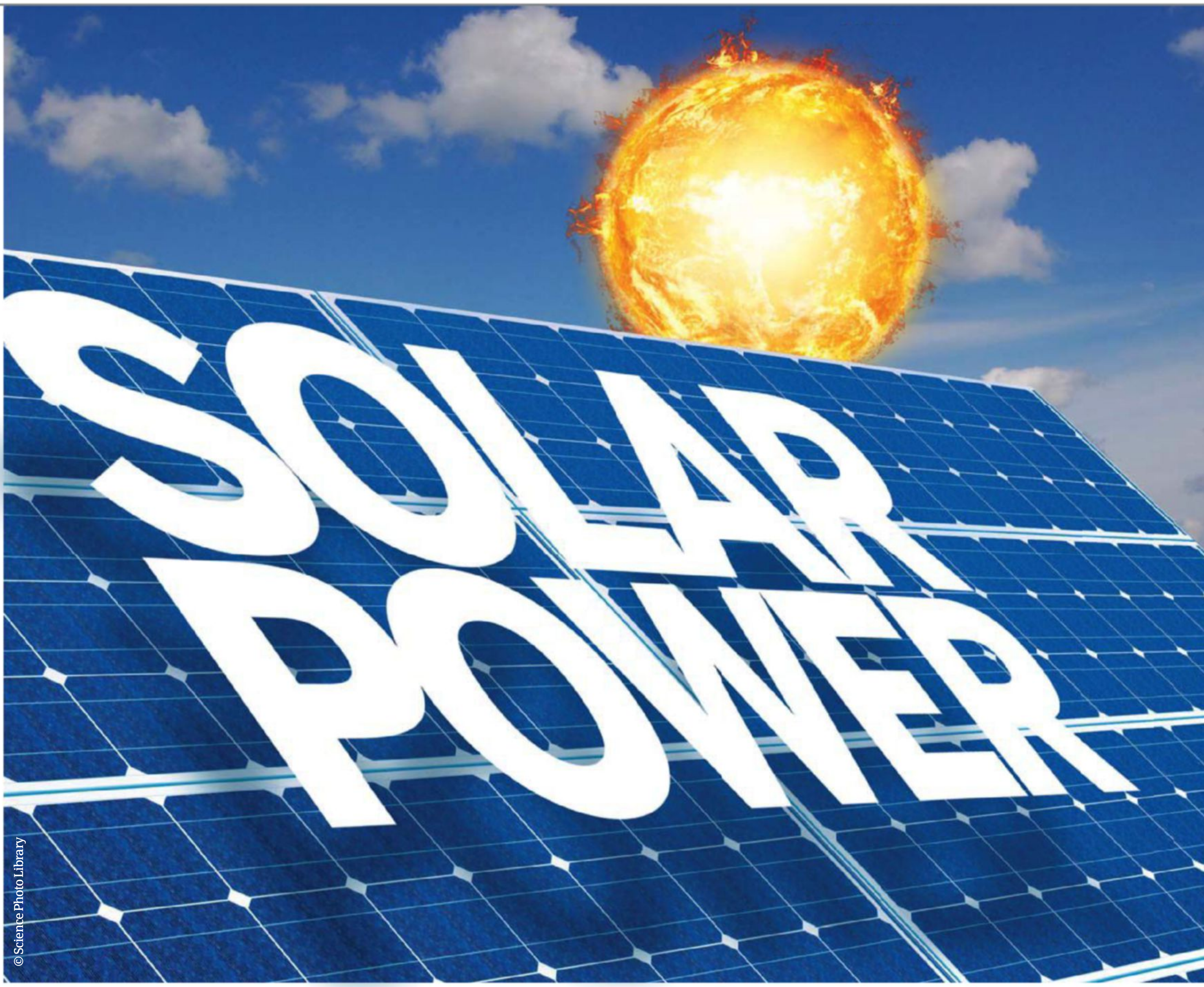
Google revolution



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Charge your gadgets, heat your home and even get paid for generating your own electricity

Renewable forms of power generation are absolutely essential. As the fossil fuels that we currently rely on begin to run out, we need to find a replacement for the world's energy needs. The impact that burning oil and gas has on the environment must also be addressed if we are to stop and reverse the effects of global warming. One of the main forms of renewable energy that has now entered the mainstream is solar power.

Capturing even just a fraction of the Sun's energy that hits the surface of the Earth could in fact mean that we are able to close our gas and coal-fired power stations. The Sun works by emitting solar radiation that is equivalent of 1,367 watts of power per square metre. This is known as the 'solar constant'.

The Sun is a massive fusion reactor, pumping out its energy (3.8 x 1026 joules per second) in all directions. On the Earth we only feel a fraction of this energy. The Sun actually delivers about 7,000 times more energy to the Earth's surface than we globally generate and use at the moment. The tricky part is capturing that incredible energy and using it efficiently.

Solar cells are properly known as photovoltaics, as the process of converting light (photo) into electricity (voltage) is achieved within the photovoltaic cell. When sunlight hits the cell, which is usually made out of silicon, it makes electrons come loose from the atoms that they are attached to. This action then produces electricity. The more sunlight that hits the cells the more electricity is produced, which you can then use in order to heat your water or charge your phone.

All across the world, every single country is looking very closely at how they can use more renewable energy sources. Not surprisingly, solar power is most popular in those countries that are lucky enough to get sustained periods of sunshine. Spain and Portugal currently lead the way with ambitious plans to develop more of their energy generation via solar power, while America is currently planning to build the world's largest solar power station.

Wind
1 Wind is actually a form of solar energy caused by the Sun heating our atmosphere. Wind farms simply use the wind to drive a turbine that generates the electricity.

Nuclear
2 Nuclear reactors work by using fission, the splitting of atoms to produce energy. That energy is used to create steam that drives a turbine to produce electricity.

Tidal
3 Tidal turbines (like under water windmills), barrages or wave turbines all use the movement of the oceans or bodies of water to generate their electricity.

Geothermal
4 Water that's been turned into steam often escapes onto the surface of the Earth. Geothermal power stations capture that steam and use it to drive turbines.

Hydro
5 From water wheels to massive dams, harnessing the energy of falling water is the basis of hydropower, making it the most efficient renewable energy source available.

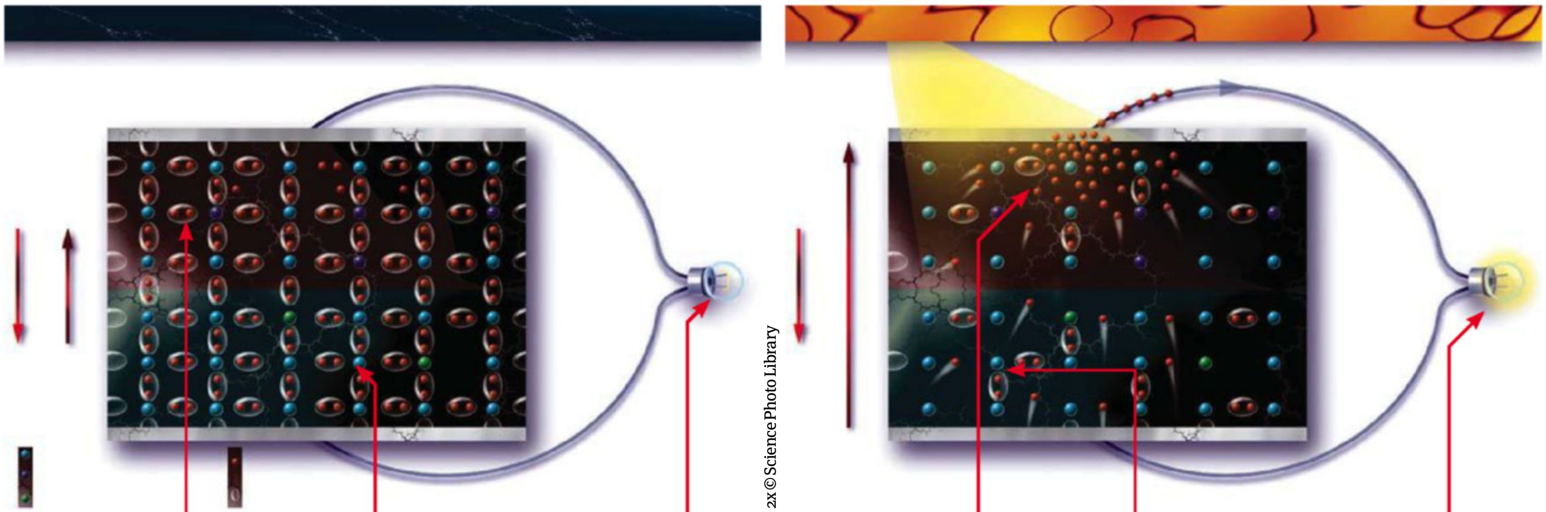
DID YOU KNOW? Horace de Saussure built the first solar collector in 1776

Photovoltaic cells in action

What goes on inside a solar cell on an atomic level?

If the sun isn't shining

If the sun is shining



2x © Science Photo Library

1. Atoms are not excited
No sunlight means that the atoms will remain at rest.

2. Sunshine will excite the electrons
Electrons will only break free when sunlight excites their parent atoms.

3. No electricity is produced
Without free-moving electrons electricity cannot be generated.

1. Electrons set free
Sunlight agitates the atoms until their electrons are set free.

2. Some atoms will remain attached
Not all atoms are dislodged to create electricity.

3. A circuit is made and electricity is produced
The metal contacts make the circuit that illuminates the bulb.

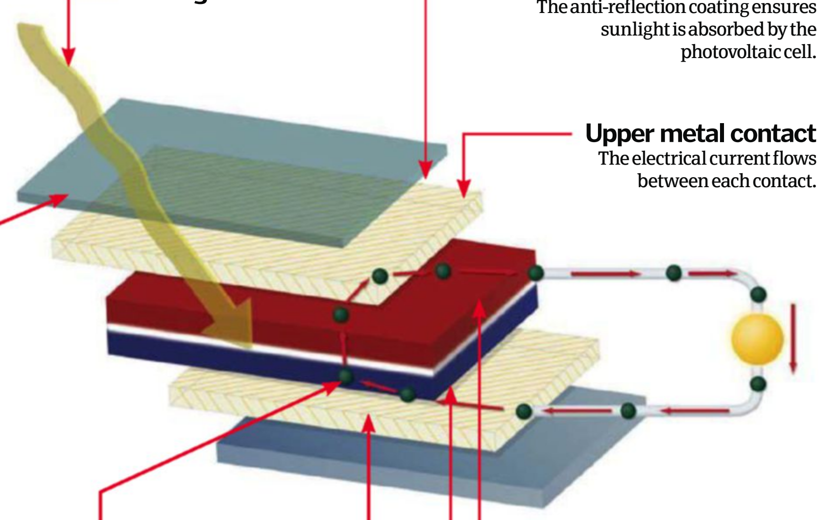
This photovoltaic barrier was built in 2001 in Freising, Germany

Sun delivers much more energy than we need should be put into context – we don't yet have highly efficient solar cells to harness the free energy. If you compare the output of your gas boiler to that of the currently available solar cells, they're only around 18 per cent efficient.

However, this is still a massive leap forward from the 3-5 per cent efficiency that early solar panels could manage. The race is now on to develop more efficient photovoltaic cells to let us capture more of the Sun's precious energy. Current research is looking at organic photovoltaics, nanotechnology and even the ability to print solar cells onto just about any surface.

How solar cells work

A layer-by-layer breakdown of what's in a solar cell and how the different parts work



Sun light

Anti-reflection coating
The anti-reflection coating ensures sunlight is absorbed by the photovoltaic cell.

Upper metal contact
The electrical current flows between each contact.

Glass cover
Photovoltaic cells need protection from the weather.

Electron transfer
Sunlight frees electrons from their parent atoms and generates electricity.

Lower metal contact
Electrical current is captured between the upper and lower contacts.

N-type (negative) silicon
Impure silicon is used to create the negative part of the circuit.

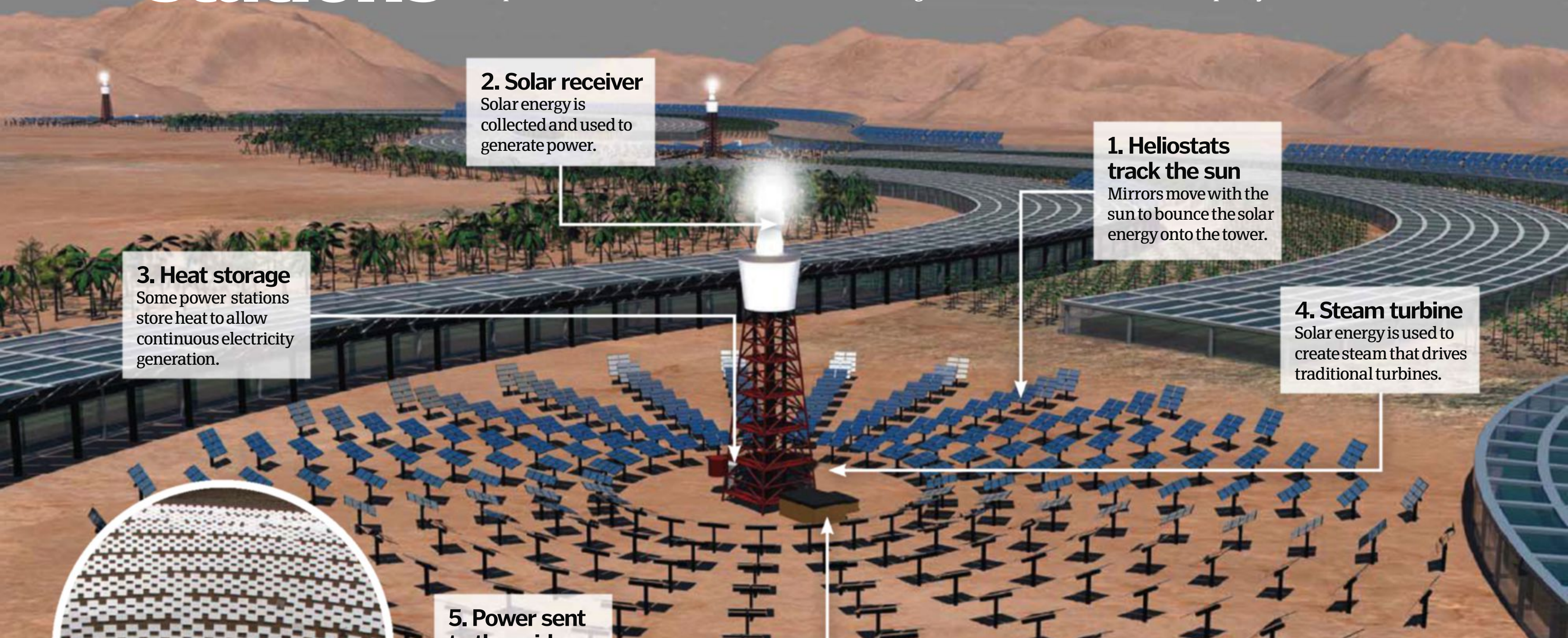
P-type (positive) silicon
Silicon with boron impurities creates the positive component of the circuit.

Solar power stations

Generating large amounts of power needs more than a few panels. Solar power stations generate electricity by creating steam that drives a turbine. The power to heat the water comes from the Sun.

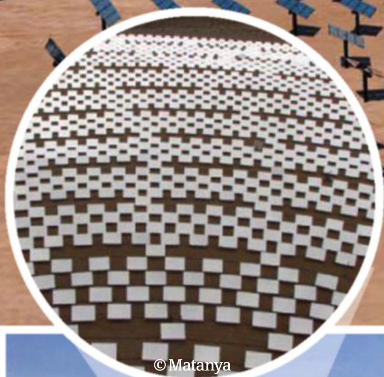
Solar power stations use a series of computer-controlled mirrors called heliostats that track the movement of the Sun and reflect its energy onto a solar receiver on top of a tower at the centre of the station. The tower contains a boiler where the water is heated. Steam is then piped to steam turbines that generate the electricity fed into the grid for distribution.

Some more advanced solar power stations also divert some of the steam generated and store this for future use. This allows the power station to stay operational even at night, or when adverse weather conditions prevent the power station working at full capacity.



The mirrors track the movement of the sun

© Science Photo Library



© Matanya

The PS10 plant in Spain has 624 heliostats

© Nosferatu.it

ON THE MAP

Worldwide solar power generators

1 UK: 17 GWh
2 Spain: 2,562 GWh
3 Germany: 4,420 GWh
4 Japan: 2,251 GWh
5 USA: 1,572 GWh
6 China: 172 GWh

SOURCE: Gross Electrical Generation – Photovoltaics - 2008

The panels come in all shapes, sizes and formations

© spg solar

Head to Head
SOLAR PANEL TECHNOLOGY

BIG

1. International Space Station
The photovoltaic arrays connected to the American modules generate about 32kW over a surface area of 375m².

BIGGER

2. Howbery Business Park
As the UK's largest array of solar panels, the 3,000-panels generate up to 682 MWh and saves 350 tonnes of CO² each year.

BIGGEST

3. Sarnia Photovoltaic Power Plant
Covering a gigantic 966,000m², the 1.3 million solar modules can generate 80 megawatts of output to power 12,000 homes in Sarnia, Ontario, Canada.

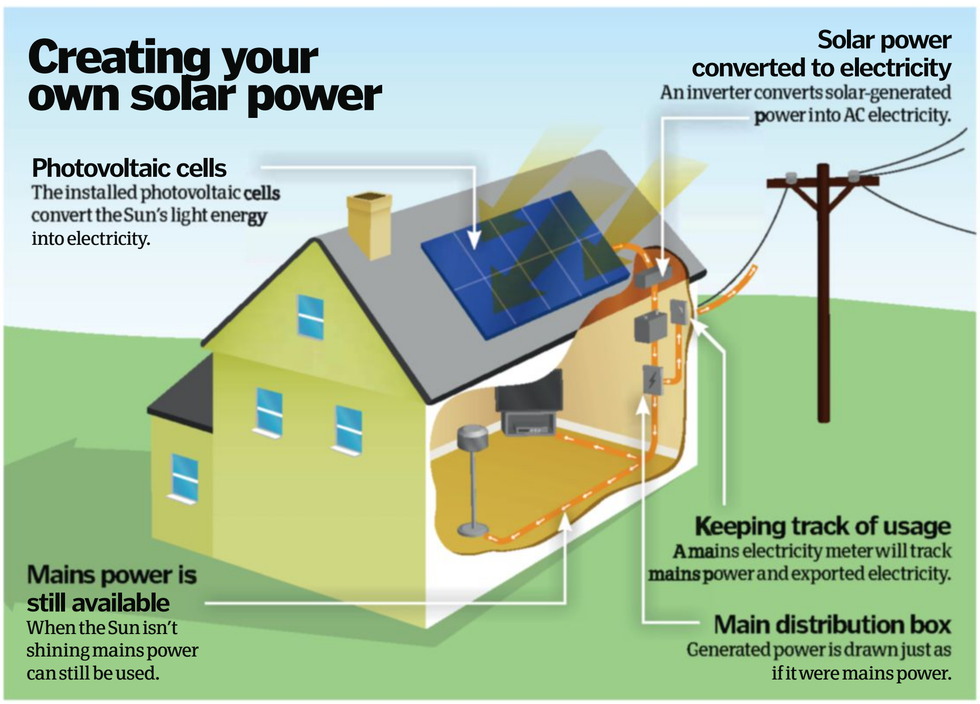
DID YOU KNOW? The Sun is 150 million km (93 million miles) away from the Earth. Sunlight takes eight minutes to reach us

How to make and sell your own electricity

One of the great things about installing solar panels at home is that you can sell any surplus electricity you generate to your local electricity supplier. The feed-in tariff, or FIT, enables anyone to gain a minimum payment for the electricity they generate.

FIT works in two ways. Your local electricity company knows you generate your own power, so fixes the payments you make for the electricity you buy from them. The other part of FIT comes into play when your photovoltaic cells generate more power than you can use. Any extra you can sell to your electricity supplier at an agreed rate. In the United Kingdom this is currently 3p per kWh (kilowatt hour).

The practical upshot of FIT for anyone who installs solar panels and produces any excess is that they will receive a payment from their electricity company on an annual basis. The photovoltaic system that you install works with a meter that not only measures how much electricity you are using from the mains supply, but also what you are generating. This is how the electricity company can calculate your payments.



Living off the grid

Life without the basic utilities might sound like a nightmare for some, but for an increasing number of people, living 'off the grid' has become a lifestyle choice. These people have not simply installed a solar panel or two, but chosen to remove themselves completely from the tether most us have to the grid and the other utility providers.

As you would expect, compromises have to be made. The amount of electricity you can generate will be dependent on the sunshine you receive, and of course there will be no long showers, nor running massive fridges when you're living off the grid.

The power that is generated is usually stored in batteries for later use, and to ensure some electricity is available when the Sun is absent. As photovoltaic cells can be attached to just about any structure or used free standing, they offer anyone who wants to live off the grid a readily available source of power.

INTERVIEW

DuPont Senior Research Fellow Dr Bill Borland

How It Works: What is the state of the solar power industry today? Has its uptake in businesses and homes been increasing?
Bill Borland: The growth of solar power has been very impressive over the last few years, but it still represents less than one per cent of global electricity production. The adoption of solar power by homes and business is primarily driven by government subsidies. Being 'green' is an added attraction. Europe, particularly Germany, has had attractive subsidies in the form of feed-in tariffs that have promoted tremendous growth in homes and businesses. Growth in other nations, such as the USA, is emerging primarily from business rooftop installations.

HIW: Could you describe the process of making solar cells?
BB: The fabrication of a conventional crystalline silicon solar cell starts with texturing one side of a boron-doped silicon wafer that will become the front face. The wafer then undergoes a high-temperature phosphorus diffusion process to form the P/N junction. After removing phosphorus silicon glass, a by-product of the diffusion process, a silicon nitride anti-reflection coating is applied to the front face. This is followed by screen-printing silver paste on the front and aluminium and silver tabbing pastes on the back. The silver and aluminium pastes are rapidly co-fired to form the completed cell.

HIW: How do current solar cell technologies differ from those used in the past, specifically with regards to efficiency?
BB: Today's six-inch monocrystalline industrial solar cell comprises a textured and passivated front face, screen-printed silver contacts and a complete metal coverage at the back. The first cell in 1953 had an efficiency of 4.5 per cent. In 1960, with the introduction of the front finger grid, efficiency leapt to 14 per cent. Full metal coverage of the back in 1972 and texturing in 1974 raised the value to 17 per cent. In 1975 screen-printed contacts became common. Wafer sizes, however, were 2-3 inches. Since 1975, effort on increasing wafer sizes to six inches, Silicon Nitride passivation in 2002 and improved contacts have created today's 17.5-18 per cent efficient solar cell.

HIW: Are there any upcoming technologies that will improve the efficiency of solar cells?
BB: The drive-to-grid parity demands improved efficiencies without increasing cost. This means changes to the conventional solar cell. Technologies like selective emitters and rear surface passivation are expected to become mainstream and each can raise efficiency by up to one per cent. Technologies on the horizon include the use of N base cells instead of P base cells. N base cells are more tolerant to impurities, making them resistant to light-induced degradation of efficiency. Other developments include metal wrap through and all back contact cells, which could deliver efficiencies greater than 20 per cent.

How dental implants stay put

Find out how high-tech artificial tooth root replacement is carried out

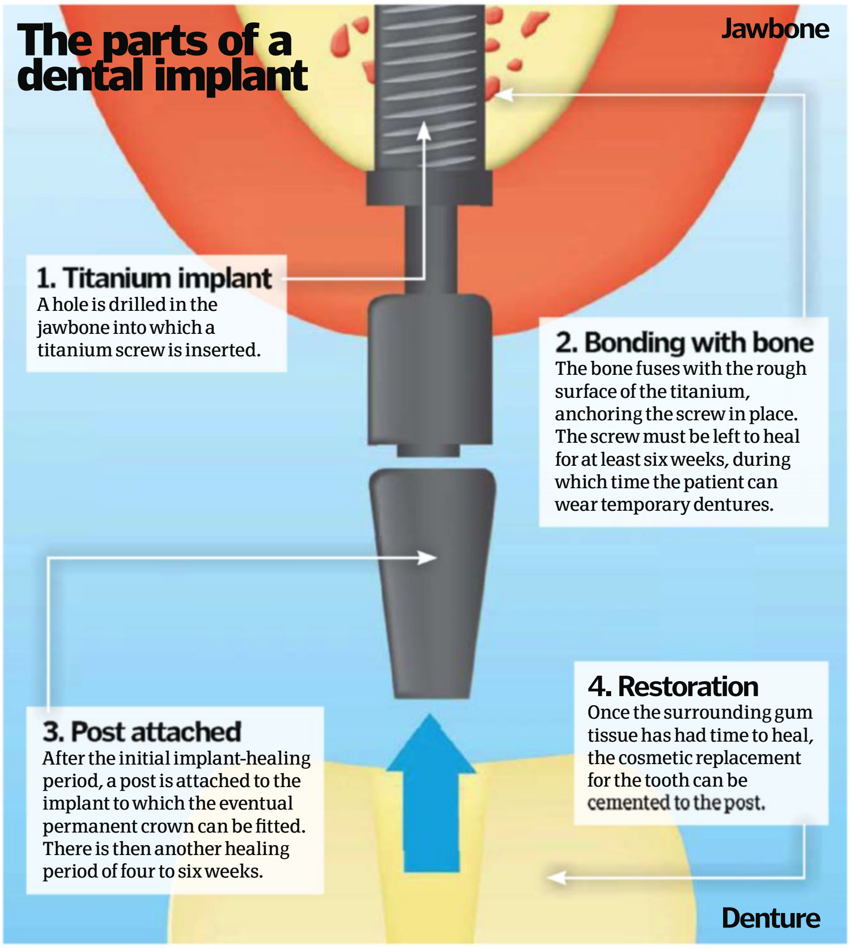
Unlike false teeth, which are removable, the dental implant is a permanent solution to tooth loss. Implants are required because when an adult tooth falls out, the root dies and the tooth will not grow back.

Affixing a dental implant is a two-stage process: first is the implant surgery, and then at least three months later – depending on how quickly the bone heals – comes the subsequent tooth restoration.

For the implant surgery, a titanium screw is inserted into the patient's jawbone under local anaesthetic. To prepare the area for implantation, the gum tissue is cut and lifted away so that a small hole can be drilled straight into the bone. The titanium screw is then tightly fitted into the hole. The great thing about titanium is that it's a material capable of osseointegrating with bone – that is it can biologically bond with the bone in the gum line, because the bone fuses with the microscopic pores in the surface of the metal. When a dental implant is embedded into the patient's jawbone, the bone gradually grows into and fuses with the implant. This screw forms the foundation for the implant and becomes the firm replacement for the natural root.

It's important that no pressure or movement is exerted on the newly implanted screw, so the space where the visible part of the tooth would appear is covered by a temporary crown. In the meantime, a permanent crown is carefully created after size and natural colour have been determined. Once the implantation site is fully healed, this final crown is then attached to the new root screw using either special cement or another screw.

The parts of a dental implant

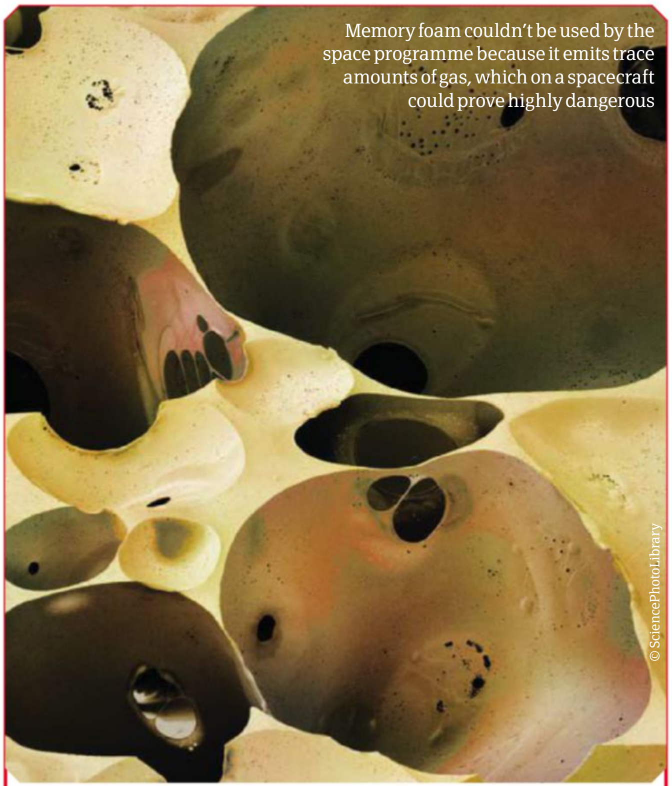


1. Titanium implant
A hole is drilled in the jawbone into which a titanium screw is inserted.

2. Bonding with bone
The bone fuses with the rough surface of the titanium, anchoring the screw in place. The screw must be left to heal for at least six weeks, during which time the patient can wear temporary dentures.

3. Post attached
After the initial implant-healing period, a post is attached to the implant to which the eventual permanent crown can be fitted. There is then another healing period of four to six weeks.

4. Restoration
Once the surrounding gum tissue has had time to heal, the cosmetic replacement for the tooth can be cemented to the post.



Memory foam couldn't be used by the space programme because it emits trace amounts of gas, which on a spacecraft could prove highly dangerous

© SciencePhotoLibrary

How does memory foam remember?

NASA's invention now used to help us get a good night's sleep

One of the most widely used NASA spin-off inventions, memory foam – also known as 'temper foam' and 'slow spring-back foam' – was originally designed with aircraft seat safety and protecting astronauts from g-forces and collisions in mind. This special plastic foam has the ability to deform under extreme pressure, absorbing the energy from crashes and providing shock absorbency while also returning to its original shape.

A foam can be a solid or a liquid that contains trapped bubbles of gas inside it. Memory foam is a solid visco-elastic foam – 'visco' (as in viscous) means that it moves when you apply pressure, and 'elastic' means it returns to its original shape when you remove that pressure. This particular foam is made from open-cell polyurethane, which is a synthetic polymer that features a network of tiny pores or bubbles that shift under pressure, rather than merely compressing. Memory foam responds to changes in temperature and tends to be firmer when it's cool but softer when it's warm. Upon applying pressure, the foam distributes the weight placed on top of it. This material has since been used for many other useful applications, such as mattresses, crash helmets, shoe insoles and even prosthetics.

5 TOP FACTS TRUMPET HISTORY

Guarded
1 In medieval England, trumpet playing was a highly guarded craft, with instruction only occurring within prestigious guilds. When in a military troop, trumpeters were closely guarded.

Ancient
2 Basic trumpets have been excavated from numerous ancient tombs. Notable locations include Egypt, Scandinavia and China. Depictions of trumpets have also been found in Peru.

Mouths
3 Orchestral players prefer wider and deeper mouthpieces, while jazz players favour narrower and shallower types. The shape and depth of the mouthpiece affects tonal quality.

Valves
4 The now common valved trumpet appeared in Germany in the 1820s. Its adoption was delayed in the US and Britain due to players and guilds committed to the older cornet-type instrument.

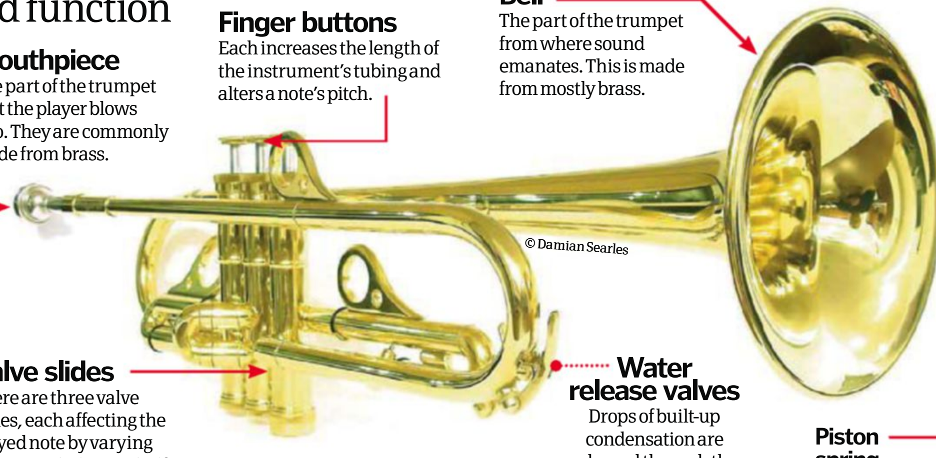
Relegated
5 From the start of the classical music period in 1750, through to the end of the romantic period in 1910, the trumpet was largely relegated by composers to a minor role within an ensemble.

DID YOU KNOW? Gochsheim Castle, Germany, has the largest collection of irons in the world, with around 1,300 exhibited

Trumpet technology

An ancient and versatile instrument, the trumpet is intricate in both form and function


Louis Armstrong was one of the most famous trumpeters



Mouthpiece
The part of the trumpet that the player blows into. They are commonly made from brass.

Finger buttons
Each increases the length of the instrument's tubing and alters a note's pitch.

Bell
The part of the trumpet from where sound emanates. This is made from mostly brass.

Valve slides
There are three valve slides, each affecting the played note by varying degrees (whole step, half step and double step).

Water release valves
Drops of built-up condensation are released through the water release valves.

© Damian Searles

The trumpet is an instrument in the brass family and, in its most basic form, is one of the oldest recorded in human history. A standard modern-day trumpet is constructed by wrapping cylindrical brass tubing twice over into a rounded oblong shape that tapers at both the mouthpiece and bell (see annotations for detail). The size and inclination of the tubing's taper determines the intonation of the instrument, and can be purposely adjusted to create different types of trumpet and sound.

Produced tone and pitch is further modified by the addition of multiple valve slides and piston valves at the heart of the tubing. These achieve this by either elongating or shortening the length air can travel through the tubing, by blocking and/or re-routing it. Finally, the shape, depth and flare of both the instrument's mouthpiece and bell also determine the quality and nature of produced sound.

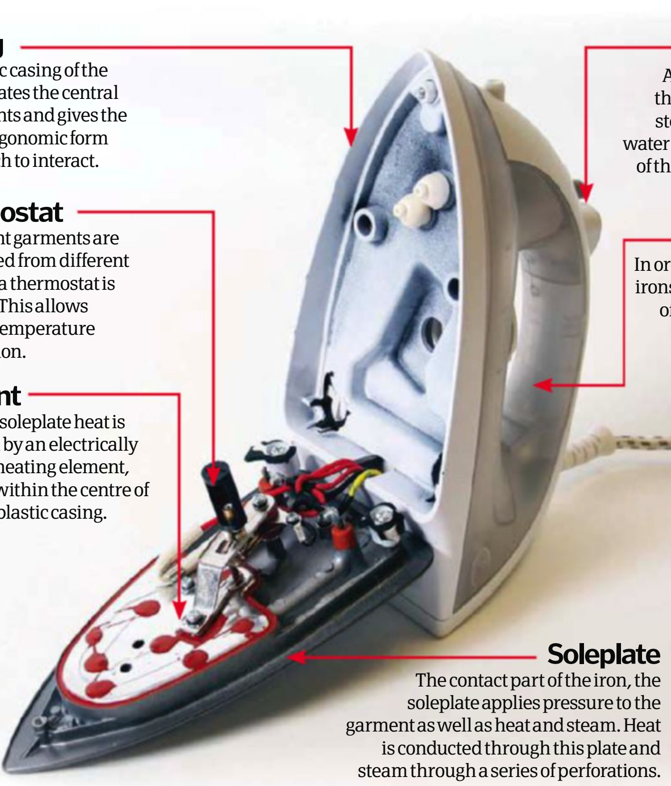
Trumpets are supplied with air from a player's mouth, which when varied in pressure and partnered with the mechanical modifiers, grant the instrument a broad playing range.

VALVE PARTS

© Guillaume Piolle

Steam iron anatomy

We break open an everyday household steam iron to see how it keeps your clothes wrinkle free



Casing
The plastic casing of the iron insulates the central components and gives the user an ergonomic form with which to interact.

Thermostat
As different garments are constructed from different materials a thermostat is installed. This allows soleplate temperature modification.

Element
The iron's soleplate heat is generated by an electrically powered heating element, installed within the centre of the iron's plastic casing.

Features
Aside from seeping steam out through the soleplate, modern steam irons also feature direct water and steam pumps at the fore of the casing, operated manually by pressing these buttons.

Reservoir
In order to produce steam, steam irons need to draw on a reservoir of water contained within the casing. This is topped up manually by the user.

Soleplate
The contact part of the iron, the soleplate applies pressure to the garment as well as heat and steam. Heat is conducted through this plate and steam through a series of perforations.


Solid irons were heated via open fires or ovens


Ironing out the facts of your everyday steam iron…

Artificial hearts

How do these mechanical organs keep blood pumping?

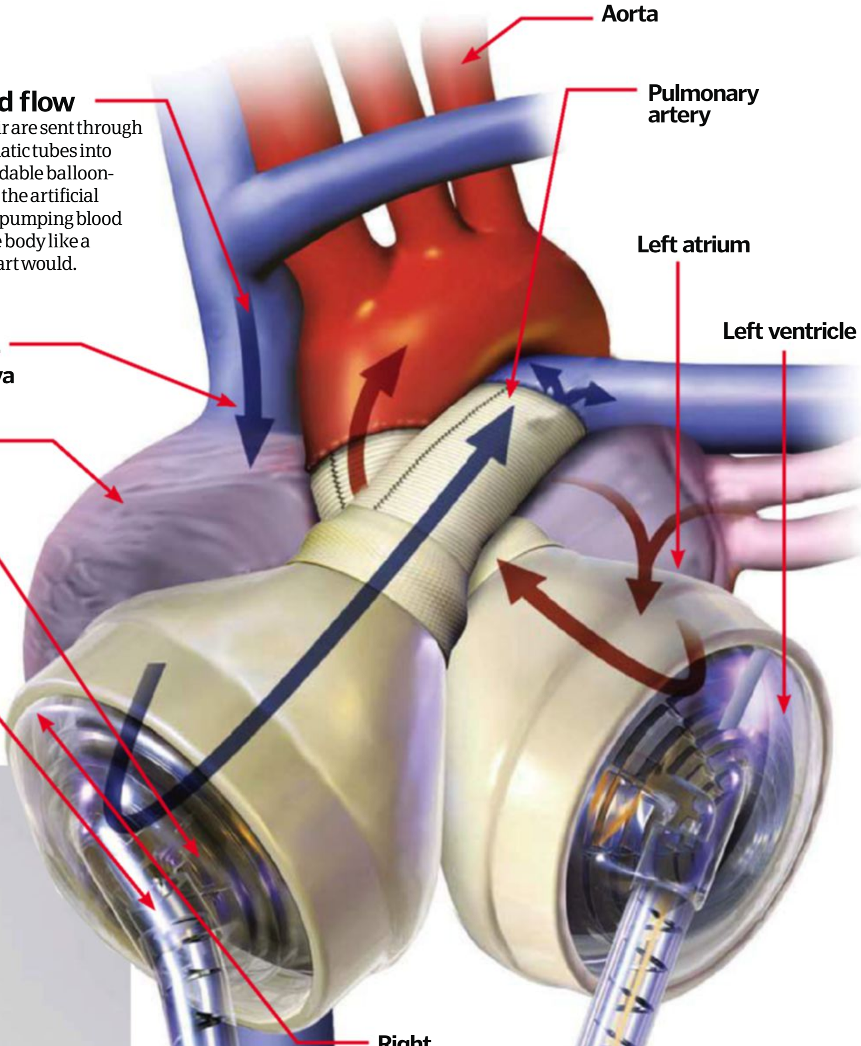
Our hearts are highly complex organs that pump about 2,000 gallons of blood around our bodies every day. A number of illnesses and conditions can lead to the heart not working properly, either progressively or more suddenly. As the heart is so crucial to keeping the human body working, scientists devised a way to replicate the role of a heart in case of its failure.

Artificial hearts are capable of replacing or assisting the pumping action of the natural organ. They can do this for many years without damaging other bodily systems, making them incredibly useful in the field of modern medicine. To implantan artificial heart, the lower two chambers (or ventricles) are removed, although ventricular assist devices (VADs) replace the entire heart in terms of functionality.

Currently, these artificial devices are a temporary solution to heart failure, and people implanted with one must still seek a real heart replacement. However, using one significantly prolongs life expectancy until a suitable donor can be found and a transplant operation carried out.

Inside SynCardia Systems' Total Artificial Heart

How this FDA-approved heart keeps ticking



4. Blood flow
Pulses of air are sent through the pneumatic tubes into two expandable balloon-like sacs in the artificial ventricles, pumping blood around the body like a regular heart would.

2. Ventricles
The ventricles of the heart are replaced with artificial plastic ventricles, with plastic tubes replicating the action of the heart's blood valves.

3. Pneumatic tubes
There are no motors nor electrical parts inside the artificial heart. Instead, pneumatic tubes passing through the skin connect it to a 6.4kg (14lb) portable unit.

SynCardia Systems' artificial heart moves 9.5 litres of blood around the body per minute

1. External pump
SynCardia's artificial heart now uses an external pump carried in a backpack to power itself, although earlier models required patients to be connected to large immobile machines.

DID YOU KNOW?

Voicing his view

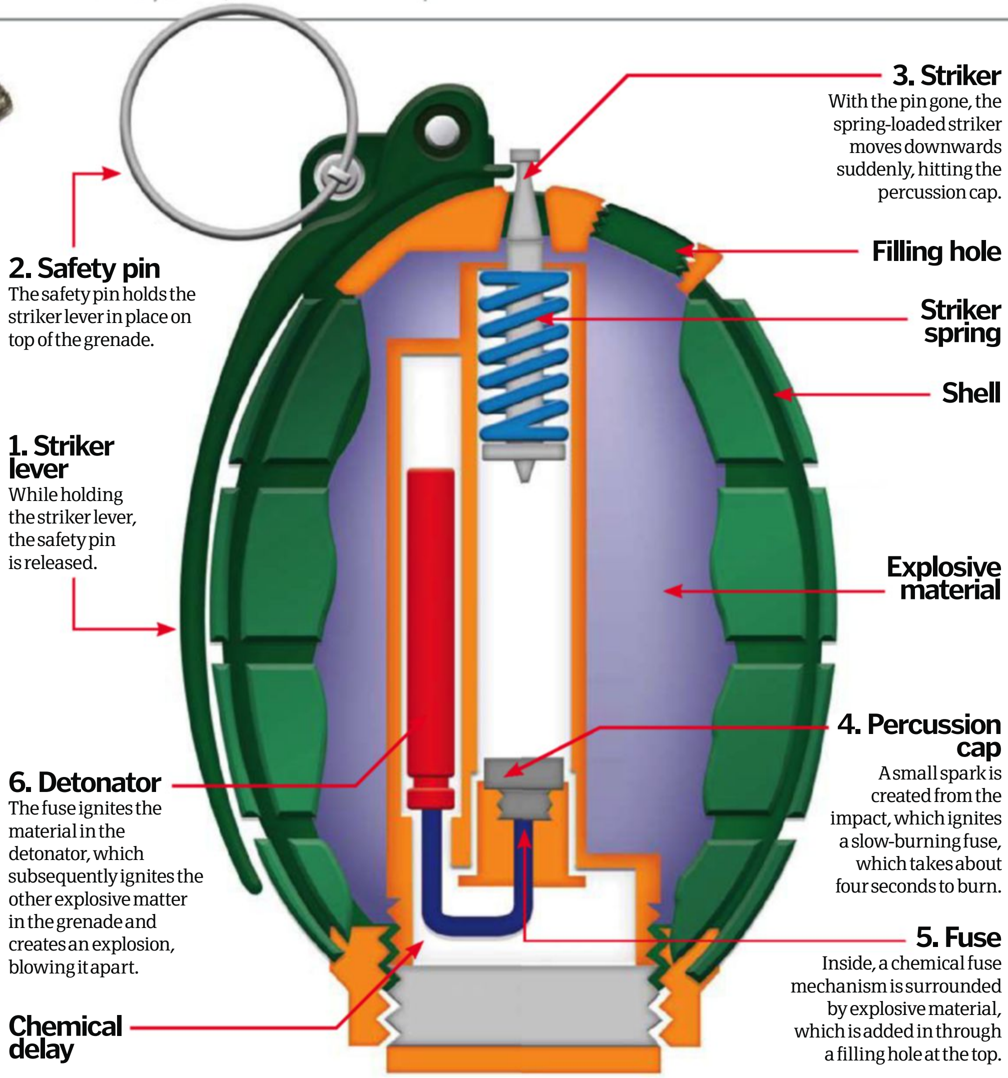
Robin Elkins patented voicemail in 1978. However, several large corporations used it without attribution and he was forced to spend a decade suing them before he was able to license the technology out and be acknowledged as its inventor.

DID YOU KNOW? *Fuse is derived from the French word fusée, which means spindle*

Hand grenades

How do these timed explosives work?

Grenades have been around for over a thousand years since the development of gunpowder allowed for these portable explosives to be made. Modern designs are influenced by these early, primitive explosives, but they are now much safer for the user and more practical. While there are several types of grenade, the time-delay grenade is most commonly used on the battlefield. These grenades are designed to fire out dozens of metal fragments in all directions. Have a look at our diagram to see just how they work.



How does voicemail record messages?

What happens after someone leaves you an answerphone message?

Voicemail works by monitoring the electromagnetic waves that are used to carry phone signals. If you are busy, or your phone is off, the message is stored in a 'mailbox', essentially another line to which calls are diverted after a certain amount of time. This mailbox records the exact nature of the electromagnetic wave that was sent, including the differences in volume and frequency in the human voice.

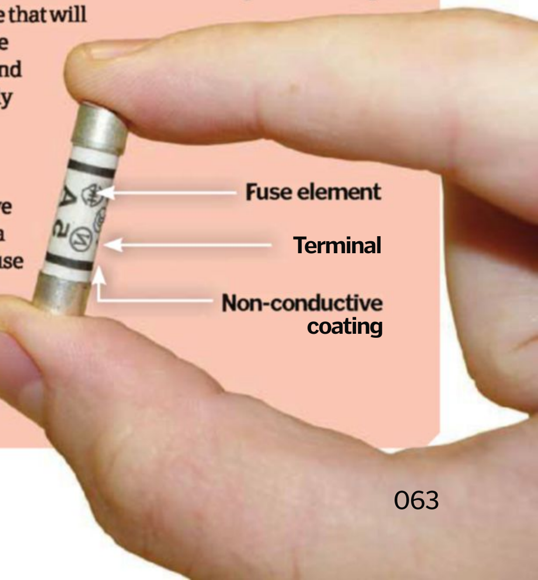
These impulses are then encoded into ASCII, a binary system that renders them into 0s and 1s. Once this is done, the phone is capable of playing it back as a stream of binary data, which includes the frequency and volume of the voice that left the message. When you hit playback, the resonating elements of the phone, including the speaker itself, use that stream of binary code to re-create the voice call for you to listen to.

How do fuses work?

Find out why blowing a fuse is actually a good thing

Fuses are essentially fire breaks, points of deliberate weakness that, if power surges through a house's electrical system, will collapse to prevent damage or fire. This is achieved by the fuse's central component, a strip or strand of metal which has a lower breaking capacity. The metal's breaking capacity is the maximum current that can be passed through it safely, while anything above that will cause it to melt and break the circuit. Zinc, copper, silver and aluminium are all commonly used as fuse wire.

The fuse wire is placed between two terminals, wrapped in a non-conductive material and put in place. If a power surge happens, the fuse will break, severing the connection, closing the circuit and thus minimising further damage.



What's inside a nuclear reactor?

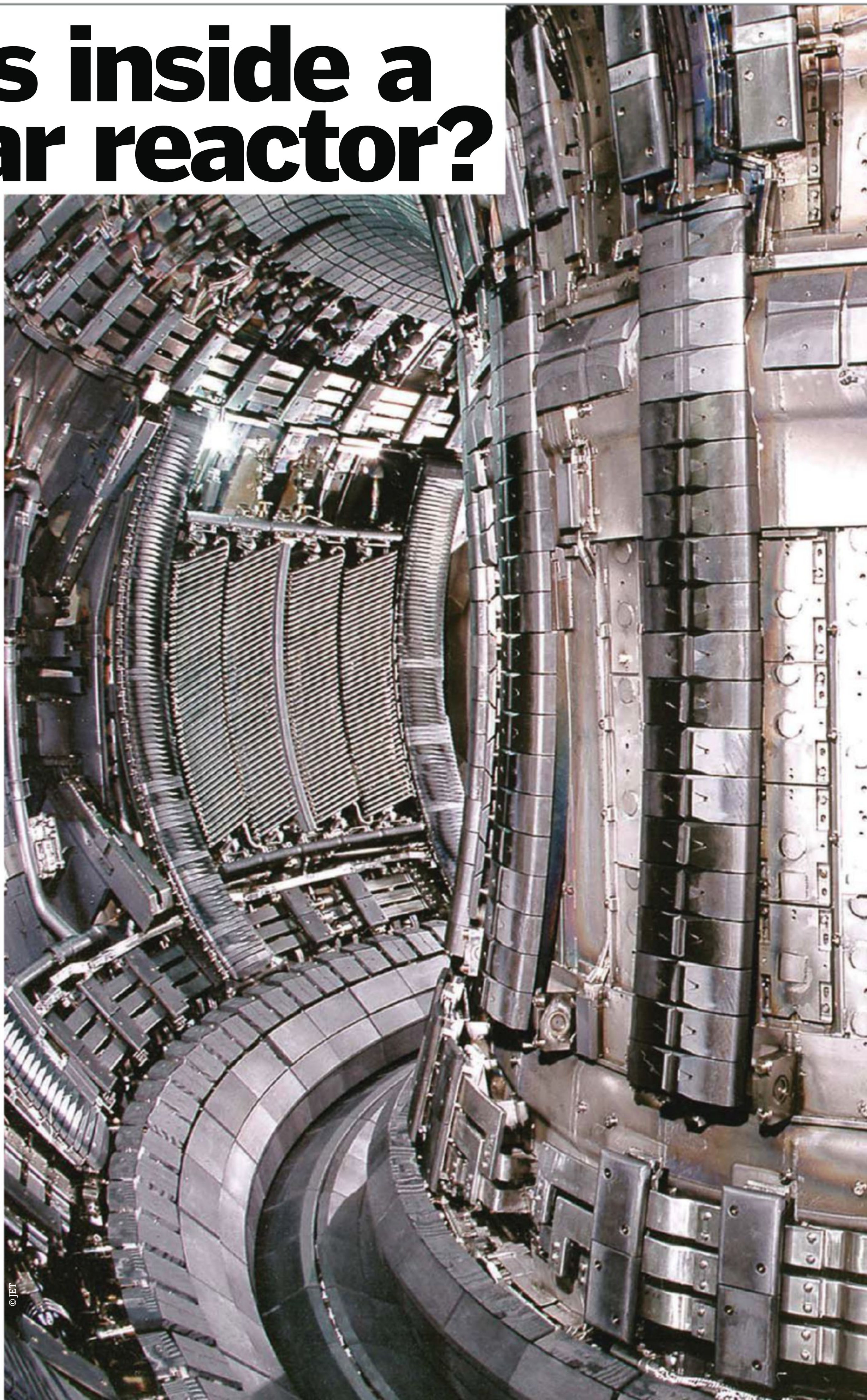
Welcome to the world's largest plasma generator

The Joint European Torus (JET) is the world's largest tokamak magnetic confinement, nuclear fusion device. The system, which is located in Oxfordshire, England, is an experimental system designed to generate nuclear reactions that are considerably more efficient and clean than those that are possible in current nuclear reactors.

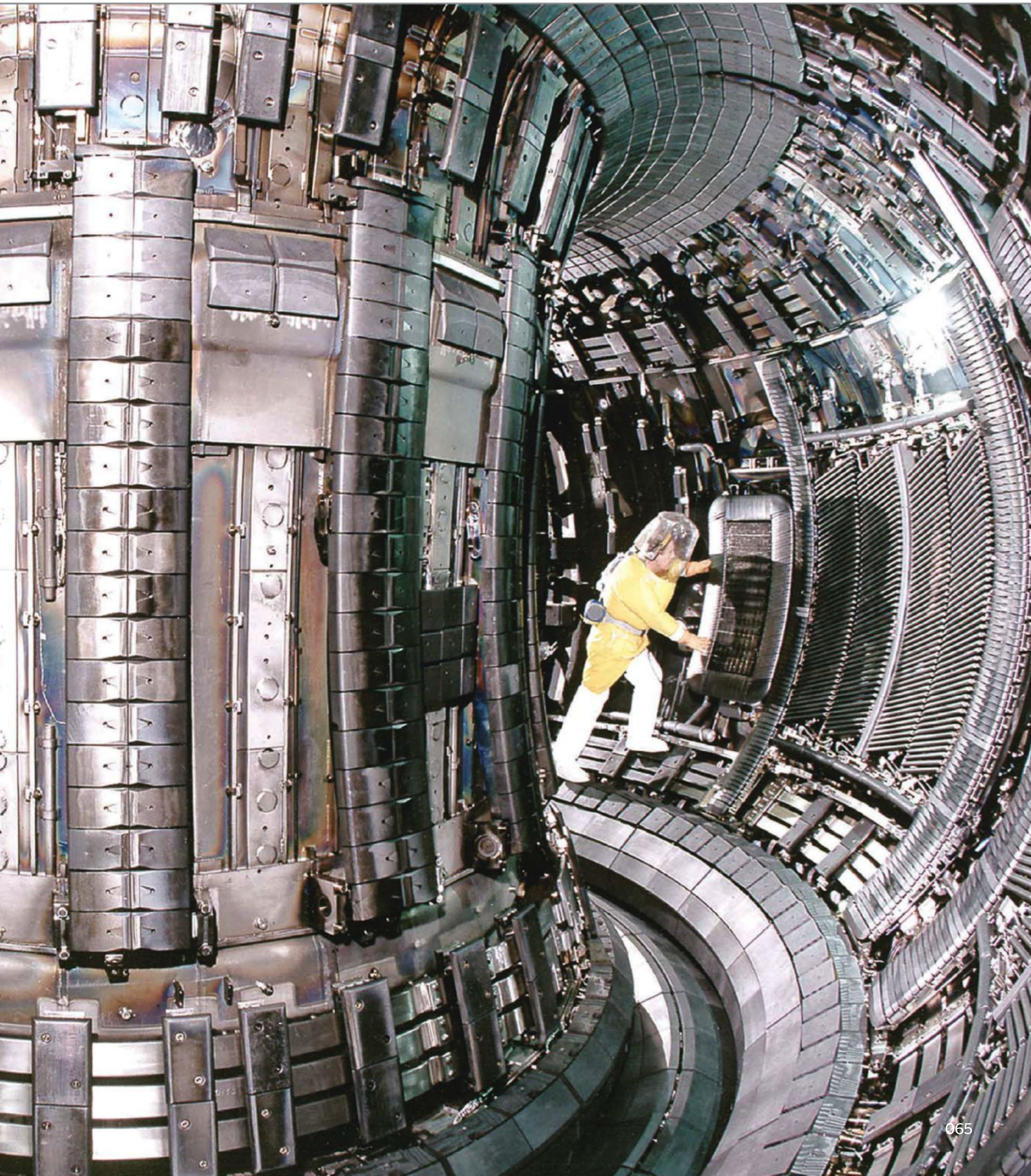
The system works by generating super-heated plasma (100 million Kelvin) and containing it within a toroidal (doughnut-shaped) container vessel. The plasma is then trapped within the device through magnetic confinement, with the charged plasma particles forced to spiral along the circling magnetic field lines running around the vessel and not onto the walls of the system. This allows the plasma to be contained as it is heated up to the level needed for nuclear fusion.

The fuel for the fusion is a gas mixture of the two heavy forms of hydrogen, deuterium and tritium. These elements are chosen as they produce the most efficient fusion reactions on Earth. The gas mix is pumped into the JET and heated in order to turn it into the aforementioned plasma where conditions force the two elements to fuse, releasing a large quantity of energy.

As of now, the JET system is being operated by a team of 350 international scientists to test the best methods of controlling the high-temperature plasma. Through this research, it is hoped that a new sustainable form of nuclear energy generation can be achieved to supply power for future generations, as well as reduce society's reliance on the rapidly diminishing fossil fuels.

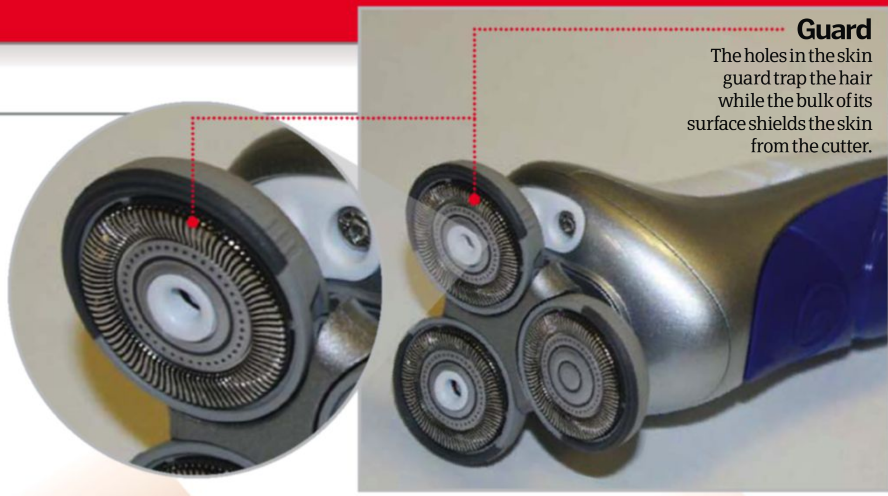


What is it? – This image shows the JET, the world's largest nuclear-fusion, magnetic confinement system in the world. Systems such as JET confine plasma within a hollow, doughnut-shaped vessel, before heating it to levels high enough to instigate nuclear fusion in order to generate useable energy.



How electric shavers work

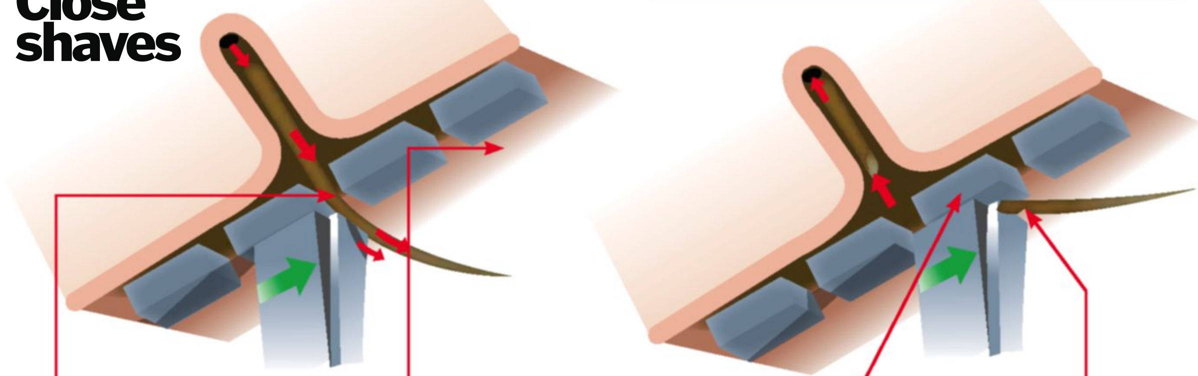
Shaving was once a contact sport, until electric shavers took the danger out of trimming your beard



There are two vital components to a shaver: the foil and the cutter. The foil lifts and traps the hair in place for the blade to cut it. Straight foil razors have very thin foils peppered with a network of holes through which the hair is pushed as the shaver moves over the skin. The cutter, positioned behind the foil, then cuts the hair. This sort of shaver can safely be pressed against the skin to make sure the shave is as close as possible.

In a rotary-headed shaver there are multiple foils – often three of them – over three separate circular blades. The foils are suspended on springs, meaning that they conform to the shape of your face when you use them, ensuring a closer shave.

Close shaves



Digital pens

How do these electronic pens transfer drawings and writing to a computer?

Digital pens, such as the Staedtler Digital Pen (pictured here), allow you to transfer handwriting, drawings, annotations and more to a computer screen, in addition to using the pen like a mouse. In the past, digital pens required special digital paper in order to work. An in-built camera on the pen would track its motion across dots on the paper, allowing the pen to locate its own position and ultimately determine what was being written. More modern digital pens, however, will work on regular paper too.

Today, however, the latest digital pens emit ultrasound and infrared waves when they're pressed to paper, as well as physically writing in ink so the user can see what they've written. The receiver, a separate component, is placed at the top of the paper. By receiving these ultrasound and infrared waves, it can accurately track the position of the pen. It can work out what shapes and characters are being written, and it can then translate this into digital data.

Up to 100 A4 pages can be stored on pens like the Staedtler Digital Pen. The data from the receiver is then transferred to a computer via USB, and handwriting-recognition software converts the writing into text. Alternatively, the receiver can be directly connected to the computer. By doing this the user can draw around objects or use the pen as they would a computer mouse.

The digital pen and receiver work together to interpret the data

"Digital pens emit ultrasound and infrared waves"

5 TOP FACTS COIN COUNTERS

Star
1 The current market leader for public currency-counting machines is US company Coinstar, which operates over 60,000 machines worldwide. They are commonly found in supermarkets.

Percentage
2 It's common for currency-counting machines to charge a percentage of the coinage sorted as payment. Coinstar charges between 8.9 and 11.9 per cent from country to country.

3 Depending on how large and commercial a coin counter is, its quantity of coins per minute (CPM) can vary. Large machines sort at 600 CPM, but smaller machines sort at lower speeds.

4 Over 28 million Britons have acknowledged that they keep money in piggy banks and other collecting containers. Of the 28 billion coins in circulation, 13 billion are in storage or misplaced.

5 Coin-counting tech is not just restricted to counting machines, but is present in many facets of society. Automated checkouts and parking meters are two widespread examples.

DID YOU KNOW? *The largest single Coinstar transaction in pennies was $13,000 in Alabama, USA*

Inside coin counters

The science of sorting and technology of tabulation explained

Currency-counting machines – such as those proliferated by US company Coinstar – work in a two-stage process, firstly separating coins by type and secondly tabulating the partial or total coinage.

Individual coin types are separated by a hopper-based filtering system, which usually involves coins being deposited onto a circular tray via a top-mounted chute, and then mechanically agitated into preset coin slots via the force of gravity. At this stage the hopper mechanism also filters out illegal or non-coinage, rejecting it via a front-mounted return chute. As the legal coins are filtered from the tray, they subsequently drop through individual funnels into a holding container, where they are mechanically weighed.

The overall weight of an individual stack of coins is then assessed by a central computer system. This has preset weight-to-value ratios logged within its tabulation software that – after the coins have been mechanical weighed and converted into a binary format – it can draw upon to calculate the coins' total value. This method of calculation – when combined with all other stacks of coin types – allows the total value of inserted coins to be determined. This information is then presented to the user via a front-mounted LCD display.

Before transactions are completed, however – affirmed by the user manually – the machine's computational software deducts a processing fee from the total coinage tabulated if the user wishes to collect/transfer the funds. This is usually around ten per cent of the total value of the inserted coins. Once completed, the coin counter generates a redeemable voucher from a front-mounted printer, which can then be cashed by store staff.

© Coinstar

Coin sorter
A mechanical hopper-based system that filters coins by size. Coins fall onto a circular tray that agitates coins into preset holes.

LCD display
User directional commands and transaction information, as well as machine advertisements, are displayed here.

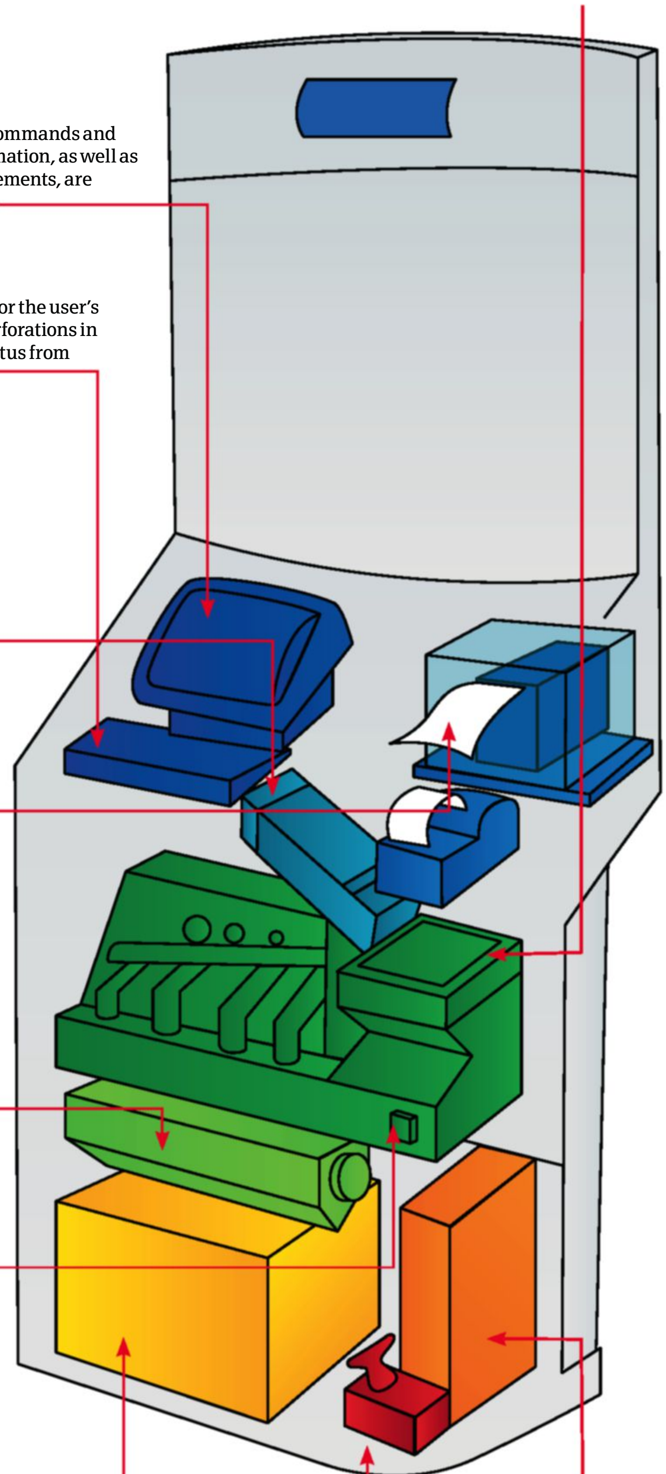
Coin tray
A depositing tray for the user's coinage. Small perforations in the tray filter detritus from the collection.

Waste filter
A slanted chute with a porous, grooved bottom plate. Liquids fall through the plate and an internal fan blows lint away.

Voucher dispenser
The total transaction – minus the processing fee – is calculated and printed here on a redeemable voucher.

Escrow tray
A tray that holds sorted and tabulated coins prior to the affirmation or rejection of the transaction by the user.

Rejection chute
Rejected transactions lead to coinage being returned to the user via a rejection chute. Foreign coinage is rejected here too.



Storage container
Affirmed transactions are deposited from the escrow tray into a storage container ready for removal by staff.

Maintenance printer
A secondary printer utilised by operating staff to receive statistical/operational read-outs from the machine.

Computer system
Currency calculation, processing fees and the operating software are controlled from a computer system.

Google™ revolution

Google doesn't just want to beat Apple at its own game, it wants to completely redefine the way we use mobile technology forever…

Exciting developments in the world of mobile technology have seen Google, one of the planet's largest tech giants, enter the tablet market with the Nexus 7.

While best known for creating the world's biggest search engine, Google has far from rested on its laurels, going on to achieve a similar accolade in the smartphone market with Android, an operating system that has eclipsed its rivals.

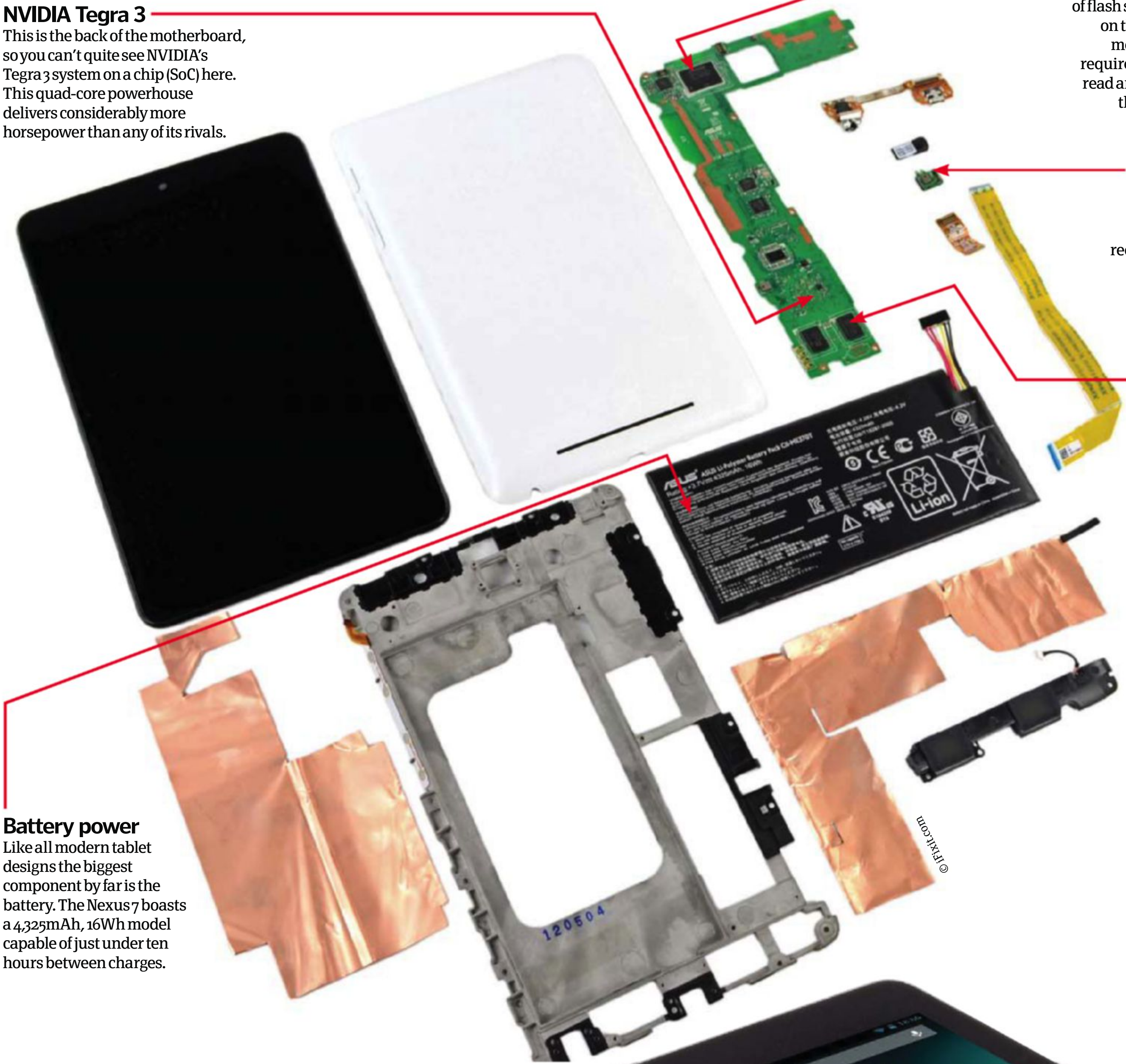
With world-leading online and mobile technologies to leverage, Google's entrance into the tablet market was a foregone conclusion, but the manner in which the company has done it has taken the industry by storm.

Far from attempting to emulate Apple's success with a similarly designed luxury 25.4-centimetre (ten-inch) tablet, Google has opted for a riskier strategy by producing a much smaller device that retails for less than half the price of Apple's new iPad. At just £159 ($199) for the 8GB entry-level model you'd be forgiven for wondering how the technology behind its 17.8-centimetre (seven-inch) screen can possibly compare, not least considering it's also half the weight of Apple's latest model. As you'll soon realise, though, the Nexus 7 is one of the most advanced consumer portable devices currently available.

How can this possibly be the case? Besides breaking even on its entry-level model by selling at almost the same price as it costs Google to build (opting to profit from subsequent app, book and movie sales from its Google Play online store), the use of NVIDIA's Tegra 3 technology is without a doubt the biggest factor. Boasting a quad-core CPU with an integrated 12-core graphics processing unit (GPU), the Nexus 7 puts Apple's dual-core CPU quad-core GPU well and truly in the shade.

Anatomy of a Nexus 7

Let's see what makes the Nexus 7 such an attractive proposition to tech geeks…



NVIDIA Tegra 3
This is the back of the motherboard, so you can't quite see NVIDIA's Tegra 3 system on a chip (SoC) here. This quad-core powerhouse delivers considerably more horsepower than any of its rivals.

8GB flash
The entry-level Nexus 7 features 8GB of flash storage, while 16GB is found on the higher-end model. Flash memory is used since it's tiny, requires very little power, and can read and write data much quicker than traditional hard drives.

Micro-microphone
One of the key features of Android 4.1 (Jelly Bean) is greatly improved voice recognition, so while this tiny microphone might seem innocuous, it's actually an incredibly important piece of the puzzle.

Memory matters
The 1GB of DDR3 RAM on board the Nexus 7 is pivotal to snappy performance and seamless multitasking. Google's tablet features twice the RAM of Apple's earlier iPads.

Battery power
Like all modern tablet designs the biggest component by far is the battery. The Nexus 7 boasts a 4,325mAh, 16Wh model capable of just under ten hours between charges.

While users will immediately notice the difference in the speed and responsiveness of everyday tasks, the Tegra 3 helps power the most impressive game graphics and hi-def video playback seen to date. Not only is 1080p video silky smooth, but it also boasts the ability to connect to HDTVs via an HDMI port.

As you'd expect, placing this kind of processing power in a device that weighs little more than a paperback puts a hefty strain on battery life, but the Tegra 3 has two mechanisms to combat this: its variable symmetric multiprocessing (vSMP) architecture and a fifth 'battery-saver' CPU.

vSMP allows each of the processor cores to be automatically and independently turned off depending on the workload. If a task is of sufficiently low power not to require any of the four 'workhorse' cores at all (eg playing music), then the fifth 'companion core' takes over completely. The whole process can occur almost instantly and is completely transparent to the operating system, the applications and, ultimately, the user.

Google's Nexus 7 tablet is not only groundbreaking in its low price point, but also in much of the technology it packs into its diminutive chassis

Augmented reality explained

What distinguishes AR from other types of reality?

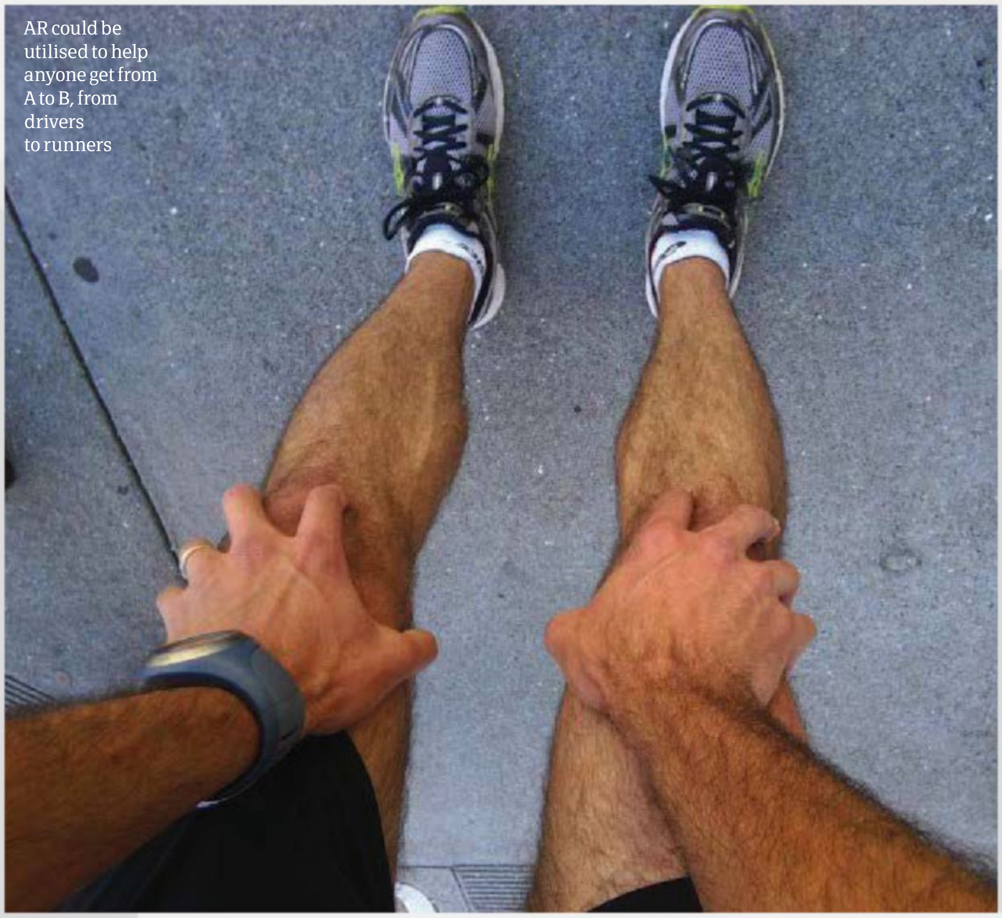
Unlike virtual reality, which attempts to create an entirely digital world separate from reality, augmented reality (AR) describes the digital enhancement of the real world using video cameras and computer technology.

While AR has actually been in use by the military for many years to power the heads-up displays in fighter pilots' cockpits, modern mobile technology is now sufficiently advanced to allow today's mobile phones and tablets to power AR applications. In the future, it will fit in eyewear (like Google's Project Glass; see below) and potentially even contact lenses.

AR works by combining live footage with GPS tracking and accelerometers to enable digital graphics to be overlaid on your devices' screens.

An AR-enabled navigation app, for example, could show a virtual arrow in the sky pointing to a distant destination. The user simply needs to walk towards their virtual target in order to find their way.

Since the AR software knows where the phone is in relation to its target (using GPS) as well as the angle and direction the device is pointing (using accelerometers), the app can precisely pinpoint where on your screen to place the virtual arrow.


AR could be utilised to help anyone get from A to B, from drivers to runners

"Augmented reality has actually been in use by the military for many years to power the heads-up displays in fighter pilots' cockpits"

Google's key milestones


© Joi Ito

1997
Google is born
Larry Page and Sergey Brin (left) collaborate on a search engine called BackRub. In 1997 they rename it Google, a misspelling of the mathematical word 'googol', a term that describes the number one followed by 100 zeros.

2000
1 billion URLs
Google goes into partnership with Yahoo! as its default search provider. Months later, Google announces that it has become the world's biggest search engine enabling users to search more than 1 billion webpages.

2005
Officially on the map
Google Maps is launched and is quickly updated to include satellite image overlays and route directions. In more recent years Google has used the same technology to create interactive maps of the Moon and Mars.

2008
Android arrives
In September 2008 T-Mobile announces and launches the G1, which is the very first phone to ship with Google's Android operating system – a massive step forward for the company. Google also celebrates its ten-year anniversary.

2011
Supercharged mobility
Google agrees to acquire Motorola Mobility, a subsidiary of the company which is credited by some with the invention of the mobile phone. The deal is reported to have been worth in the region of £7.9 billion ($12.5 billion).

"Google has created interactive maps of the Moon & Mars"

A glass act

Pushing the envelope even further than the Nexus 7 and Nexus Q combined is Google's Project Glass, a rather ambitious attempt to bring 'wearable computers' to the masses.

Project Glass is effectively a pair of 'smart' glasses that features a tiny screen that sits above the normal plane of vision of the right eye and displays augmented reality (AR) prompts utilising all of Google's extensive intellectual properties. Google Maps and Navigation will, for example, be used to show you the way to a Google Calendar event, or it could allow you to have a Google+ 'Hangout' video chat with a circle of friends while you're on the long commute back from work.

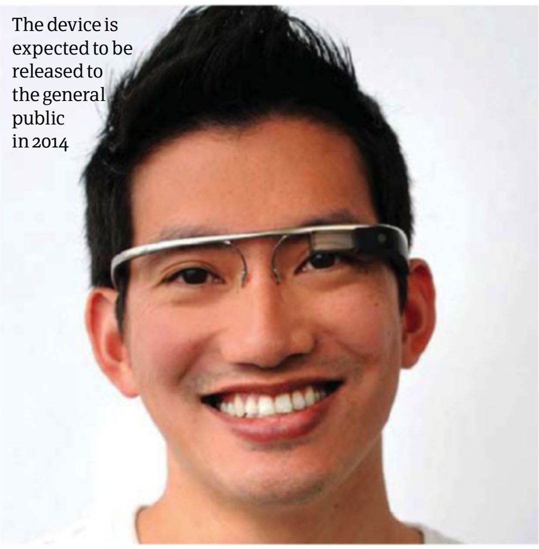
The device is currently in the prototype phase, but Google expects to ship the glasses during 2013 to developers, before releasing them to the general public in 2014 for around the same price as a smartphone.

While little is still known about how the device itself will work, it is expected to feature both Wi-Fi and Bluetooth capabilities and will be controlled by small tilts of the head (sensed by accelerometers) and by actively studying the wearer's line of sight. According to Google's video demonstration, the wearer simply needs to look up to prompt a menu bar, then glance left and right to make selections to check the weather, make and receive calls or activate voice-recognition software to compose text messages, among other things.

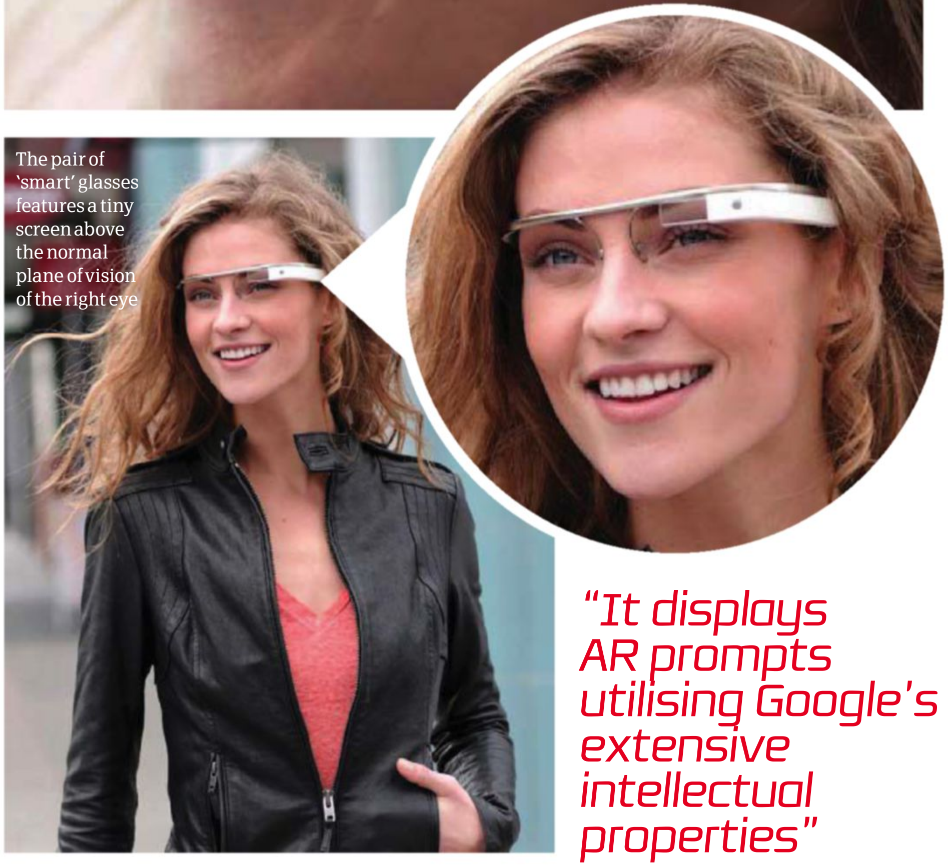
While more specific workings of the device are yet to be revealed, it's likely that Project Glass will operate by being 'paired' wirelessly with your Android smartphone allowing the latter to provide much of the computational power for the AR glasses remotely. Google has confirmed, however, that the device can be worn by itself, or even fixed to a pair of existing glasses.

It's also worth noting that Google recently patented a motion-based theft-detection mechanism that essentially deactivates and locks the glasses should they ever sense a sudden or 'unnatural' movement, laying to rest the notion the project is vapourware (that is, purely conceptual).

Project Glass aims to bring 'wearable computers' to the masses



The device is expected to be released to the general public in 2014



The pair of 'smart' glasses features a tiny screen above the normal plane of vision of the right eye

"It displays AR prompts utilising Google's extensive intellectual properties"

How Siri works

Apple's personal assistant isn't magic but the culmination of 60 years' development into natural language processing

Pivotal to Siri's operation is natural language processing, a field of computer science and linguistics that has slowly advanced over the past 60 years. Natural language processing, which itself contains myriad sub-processes such as speech segmentation, is the overarching system that allows Siri to accurately – in most cases – respond to your commands. Key to the whole function, however, are statistical models.

Statistical natural language processing, as used by Siri, employs chance and probability to resolve the required range of sub-processes. These processes often use corpora (a large volume of known, real-world data) to derive a set of abstract rules from which to interpret received data (ie your voice command), in addition to a statistical model, such as the 'hidden Markov model' (HMM).

The HMM is a statistical system that, through probability and mathematical algorithms, analyses a spoken command's sequence of phonemes (the smallest unit of spoken sound) to generate a chain – the completed chain forming a single word. It does this by assigning a probability score to each phoneme, before determining which word the individual phonemes amount to.

The statistical models, however, rely on the system's training data – eg the corpora – referencing acoustic models, word lists and probability networks at multiple points. This is because while the system is finely tuned to deliver completed chains, the chain and the chain's context – be that meaning or position within an extended command – varies depending on non-statistical variables.

Due to the vast complexity and processing power necessary to analyse any spoken command, the majority of Siri's natural language processing is handled in the cloud, with a handset consulting remote servers to quickly supply a response. This process is explored in detail in the 'Speech to text step-by-step' diagram above.

Defibrillators explained

How this machine gets the heart back on track

An automated external defibrillator (AED) sends a burst of electrical energy through the chest wall to the heart. It is used on people suffering from life-threatening fast heart rhythms or when the cardiac muscles are working in an uncoordinated fashion (also known as ventricular fibrillation). The shock briefly stops electrical activity in the heart and, with any luck, enables it to return to a regular rhythm.

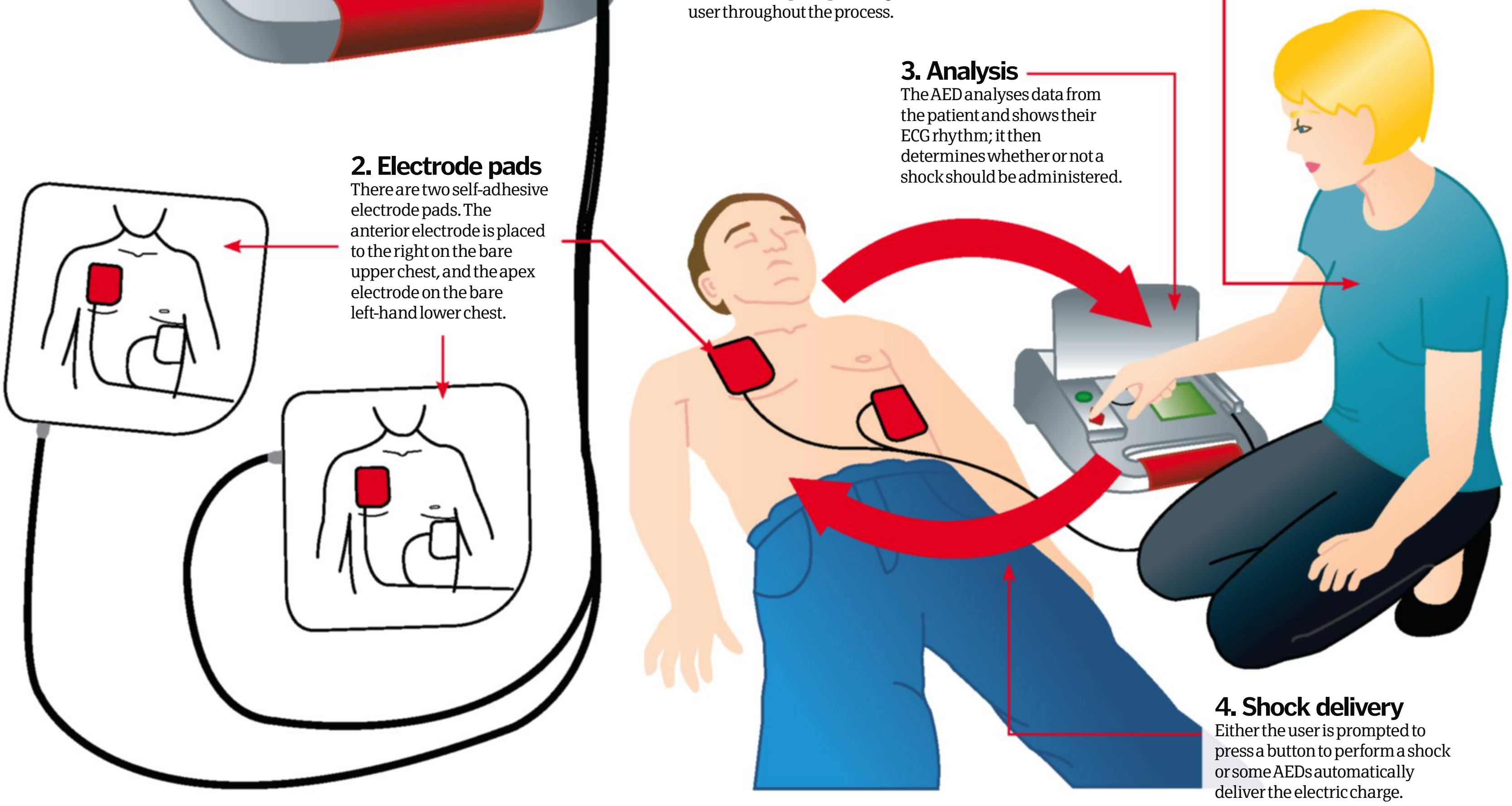
The defibrillator consists of a large capacitor that is charged by a battery. A typical AED has a capacitor that stores a massive 970 joules of energy and delivers 4,200 volts in a matter of milliseconds through the electrodes positioned on the patient's chest.

A microprocessor inside the AED decides whether a shock should be administered based on the ECG (electrocardiogram) reading from the electrodes. In other words, it will not allow someone with a healthy heart rhythm to be shocked.

The electrodes should be securely attached to the victim, and they should not be touched during the shocking process. The use of CPR (cardiopulmonary resuscitation) chest compressions is advised before and after the AED is brought into action.

"An automated external defibrillator sends a burst of electrical energy through the chest wall to the heart"

Using an automated external defibrillator



1. Display panel
This shows the operator diagrams illustrating how to assess the patient. This information is supplemented with text and voice prompts that guide the user throughout the process.

2. Electrode pads
There are two self-adhesive electrode pads. The anterior electrode is placed to the right on the bare upper chest, and the apex electrode on the bare left-hand lower chest.

3. Analysis
The AED analyses data from the patient and shows their ECG rhythm; it then determines whether or not a shock should be administered.

4. Shock delivery
Either the user is prompted to press a button to perform a shock or some AEDs automatically deliver the electric charge.

5. CPR
CPR chest compressions should be carried out on the patient before the AED arrives, and when prompted by the device.

2x © BAE Systems

NEXT-GEN ROBOTICS

ROBOTS ARE MAKING GREAT STRIDES – QUITE LITERALLY – SO THE UPCOMING FEW YEARS PROMISE TO USHER IN A WHOLE NEW ERA FOR AUTOMATONS

Without a doubt, robots have captured the imagination of science-fiction writers and filmmakers over the last 80 years, but even the best efforts of engineers have so far fallen short of the vision of the graceful, intelligent, self-aware machines that aim to kill us, love us or become more human.

The application of advanced systems and technology throughout the modern world begs a re-evaluation of the question: what is a robot? Going back to the basic definition of the word, which comes from the Czech *robota*, meaning forced labour, a robot could be anything that performs a physical task for a user.

Available technology has generally limited robot development relative to the imagination of writers and filmmakers. Computer processing capability is currently at a level that allows very sophisticated software to be used, with a large number of advanced sensors and inputs giving huge amounts of information for the software to utilise. One example is the Samsung Navibot, which negotiates its environment with a host of sensors and clever programming to map a room, store the room shape in its memory, define its position and vacuum-clean the floor before returning to a special dock to recharge itself.

Decades of research and development in key areas have begun to pay off, with significant weight reductions and increased structural strength made possible by advancements in carbon fibre and composite material technology. Mechanical and ergonomic research has been instrumental in domestic and care applications, such as the Japanese robot RI-MAN, which easily lifts patients in care homes to save both staff and patients risking injury. Robot/human interaction research is also allowing machines to be tailored to be more widely accepted and trusted, especially with vulnerable or disabled users. NAO is a good

Titanoboa, an exciting project led by Charlie Brinson, is reincarnating a one-ton electromechanical snake

Domestic

ASIMO

Application: Technology demonstrator

Status: Continual development

When it will replace humans: Unknown

Info: The all-new ASIMO is lighter and more streamlined than ever. Its new smaller body belies the awesome tech within though, with ASIMO now capable of improved capabilities (such as talking while delivering drinks) thanks to advanced AI systems and considerably improved movement. ASIMO now has 57 degrees of freedom, can run at 9km/h (5.6mph) and communicate via sign language.

5 TOP FACTS CUTTING-EDGE BOTS

ASIMO

1 Developed over 20 years by Honda, ASIMO pushes robot tech in every area, being a pioneer of walking, running, robot/human interaction and environmental awareness.

Robonaut 2

2 Developed for the International Space Station (ISS), the Robonaut is a waist-up humanoid torso. With arms and fingers, it is able to use tools designed for humans.

Taranis

3 Far superior to a manned aircraft and able to make its own decisions about taking human life, BAE's Taranis really takes us into the terrifying realms of science fiction.

Curiosity Mars rover

4 Intelligent, semi-autonomous and jam-packed with scientific apparatus, including a laser and nuclear battery, this car-sized robot has all it needs to study the Red Planet.

da Vinci medical robot

5 Able to assist or conduct operations remotely under the control of a surgeon, the multiple arms of this machine point towards an exciting relationship between robots and doctors.

DID YOU KNOW? ASIMO was able to move in such a humanlike manner, Honda sought blessing from the Vatican to develop it

BAE SYSTEMS' POINTER ROBOT

Military

BAE Pointer

Application: Soldier

Status: In development

When it will replace humans: 2020

Info: BAE's Pointer is a concept vehicle recently presented to the UK government as part of its Future Protected Vehicles programme. The Pointer is a robotic soldier designed to carry out repetitive or dangerous reconnaissance work in the field, eg sweeping for mines. It can travel at high speed on its horizontal tracks or walk like a spider. Its body was designed to be modular, allowing for a variety of configurations, be that a support of human troops with an autocannon, acting as a medibay or delivering battlefield intel as a highly mobile mechanised scout.

ROBOT LAWS

Science-fiction writer Isaac Asimov introduced the three laws of robotics in a 1941 story. These are:

1 A ROBOT MAY NOT INJURE A HUMAN BEING, NOR THROUGH ITS INACTION ALLOW A HUMAN BEING TO COME TO HARM

2 A ROBOT MUST OBEY THE ORDERS GIVEN TO IT BY HUMAN BEINGS, UNLESS SUCH ORDERS WOULD VIOLATE THE FIRST LAW

3 A ROBOT MUST PROTECT ITS OWN EXISTENCE, AS LONG AS THIS DOES NOT CONFLICT WITH THE FIRST TWO LAWS.

BAE SYSTEMS' TARANIS ROBOT

Military

BAE Taranis

Application: Unmanned combat air vehicle (UCAV)

Status: In development

When it will replace humans: 2018

Info: BAE's Taranis is named after the Celtic god of thunder and has been designed to explore how an autonomous vehicle – controlled by a team of skilled, ground-based operators – can perform many of the roles undertaken by human pilots while remaining non-detectable to radar. Due for flight trials this year, the Taranis relays info back to command at which point it can engage a target if it sees fit.

Although the Taranis will ultimately be controlled by a team on the ground, it will still be able to make its own judgement calls within a preprogrammed remit

example of this as its cartoon-like features make it look friendly, which is ideal in its role of supporting the teaching of autistic children.

Integration with other technologies is another key capability that is making a huge difference to development, with existing global positioning systems and communication networks allowing autonomy at never-before-seen levels of accuracy, cost and reliability.

The internet has proven invaluable in offering access to similar lines of research, the sharing of open-source materials and the easy exchange of opinion and resources, which benefits the improvement of technologies. One interesting use of the web is to easily and reliably control robotic systems from anywhere in the world, allowing machines like the da Vinci medical robot to be used by the best surgeons on the planet, while in a different country to the patient if necessary.

Military applications have traditionally pushed the development of technology, and robotics is an area that is benefiting from this, with many unmanned and autonomous aircraft, tracked and wheeled vehicles, snakes and microbots being designed to suit the modern battlefield. Assets such as BAE's Taranis robotic stealth fighter promise high capability, high autonomy and come at a high price, but the development of low-cost, flexible solutions for information gathering, bomb disposal and troop support is evident with the stealthy snake-like robots making excellent progress with several armies, and systems like BAE's Pointer and Boston Dynamics' LS3 taking over many repetitive, dull and risky jobs.

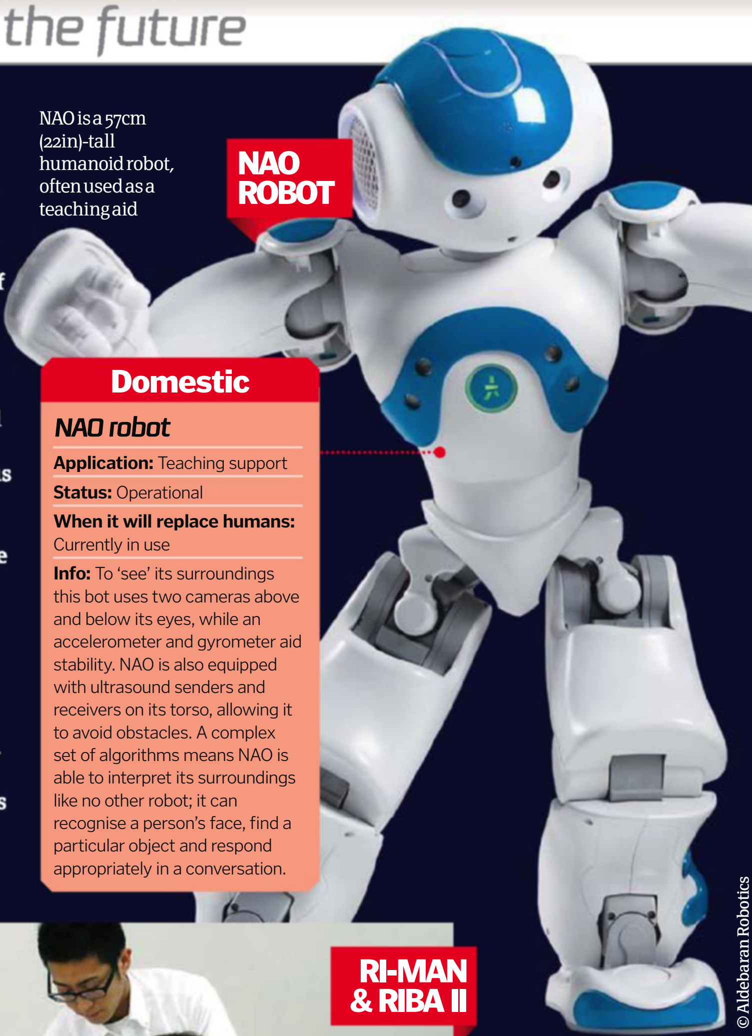
We see the benefits of these next-gen robots every day. Autonomous satellites provide GPS navigation for our cars, as well as data links for our mobile phones and computers. Cutting-edge robot technology is making the mass production of items from drinks cans to cars evermore efficient and cost effective, thanks to the progression of industrial robotic systems. Unmanned warehouse and production-line robots move goods around factories, while the level of autonomous control that modern cars have over their brakes, power and stability systems to improve safety takes them very close to the definition of a robot. The mass-market autonomous car is likely only a few years away, with most major manufacturers such as Volvo and BMW having developed driverless technology demonstrators, but it is the human element in this holding the systems back more than the technology, as many people feel very uncomfortable putting their lives in the 'hands' of a robot driver.

Scientific and space research is an area to which next-gen bots are well suited, with machines such as the

NASA Dawn spacecraft excelling in their roles. Using an advanced ion engine to move around the solar system, this small, low-budget craft is performing a mission which would be impossible with manned systems. Similar robots can keep humans out of danger in arctic, deep-sea or volcanic research as conducted by the eight-legged Dante II in 1994.

We are on the verge of further technological breakthroughs that will transform the capabilities of robots. The quantum computer may be with us in just a few years, and could give a huge increase in processing power while power-generation tech has made a huge leap recently with lithium-based systems. Traditional motors for controlling robots may be replaced with new tech based on expanding/contracting memory metals, electro-reactive materials or other means proving to be more efficient or precise. The next generation of robots is now arriving; who knows what's waiting around the corner?

NAO ROBOT



NAO is a 57cm (22in)-tall humanoid robot, often used as a teaching aid

© Aldebaran Robotics

Domestic

NAO robot

Application: Teaching support

Status: Operational

When it will replace humans: Currently in use

Info: To 'see' its surroundings this bot uses two cameras above and below its eyes, while an accelerometer and gyrometer aid stability. NAO is also equipped with ultrasound senders and receivers on its torso, allowing it to avoid obstacles. A complex set of algorithms means NAO is able to interpret its surroundings like no other robot; it can recognise a person's face, find a particular object and respond appropriately in a conversation.

Domestic

Samsung Navibot

Application: Cleaning

Status: Developed product

When it will replace humans: On sale now

SMART CLEANING

The Samsung Navibot has 38 sensors to map rooms, avoid bumps and recharge itself

1. Looking up
The top houses the infrared roof sensor that shows Navibot the shape of the room.

2. Brush
Following an efficient pattern within the room, the power brush sweeps the whole floor.

3. Suck-up
Dust is sucked up into the bin by the powerful vacuum, from both carpet and smooth floors.

4. Teeth
The brush pulls through teeth inside the body, next to infrared sensors which detect drops.

5. Hair-free
The anti-tangle system ensures that no long strands of hair jam up the rotating brush.

6. Allergy
The hyper-allergenic filter can be cleaned and the vacuum can be set to operate daily.

© Samsung

2x © Harvard University

RI-MAN & RIBA II

RIBA II can lift people weighing up to 80kg (176lb)

2x © Provided by RIKEN-TRI Collaboration Center for Human-Interactive Robot Research

Domestic

RI-MAN and RIBA II

Application: Care work assistance

Status: Operational

When it will replace humans: Currently in use

Info: RIBA (Robot for Interactive Body Assistance) evolved RI-MAN's ability to lift and set down a human; RIBA II can lift up to 80kg (176lb). Joints in the base and lower back allow the bot to crouch down to floor level, while rubber tactile sensors enable it to safely lift a person. These sensors let the robot ascertain a person's weight just by touching them, so it knows how much force to apply when picking them up.

ROBOTIC LANDMARKS

1938
Auto paint sprayer
Harold Roselund and William Pollard pioneer industrial production robotics with an automated paint-spraying arm.

1939
Elektro
While stories depicted intelligent, humanlike robots, this mechanical man appeared at the 1939 World's Fair.

1948
Robot tortoise
With autonomous roaming, obstacle avoidance and light sensitivity, this bot was well ahead of its time.

1950
Isaac Asimov
I, Robot, the book that defined our modern take on robots, was based on Asimov's three laws of robotics.

1954
Programming
The first programmable robot was designed by George Devol, who started Unimation, the first robotics company.

© NASA

Head to Head
MEAN MACHINES

TOUGH

1. Wheely Big Cheese
A favourite from the TV show *Robot Wars*, Wheely Big Cheese is made of titanium and is powerful enough to flip a car.

TOUGHER

© QinetiQ North America

2. TALON IV
This tracked robot, which is currently used in many search-and-rescue roles, can also carry machine guns and cannons if firepower is required.

TOUGHEST

3. Taranis
BAE's large robotic fighter-plane can carry a range of weapons, employ stealth technology and fight multiple enemies without any human involvement.

DID YOU KNOW? Future planet exploration may be done with robot snakes and spiders, as wheels can struggle in this terrain

Lifesaving
'Soft Robot' Starfish

Application: Search and exploration

Status: In development

When it will replace humans: 2025

Info: Scientists at Harvard University are engineering flexible, soft-bodied (elastomeric polymer) robots inspired by creatures like squid and starfish. Capable of complex movements with very little mechanisation, this sort of bot could be used in search-and-rescue operations following earthquakes. The multi-gait robot is tethered to a bottle of pressurised air, which pulses through the hollow-bodied robot to generate simple motion.

EMILY featured in the top ten of *TIME Magazine*'s 50 best innovations of 2010

LIFESAVING LANYARD

2x © Hydronalix

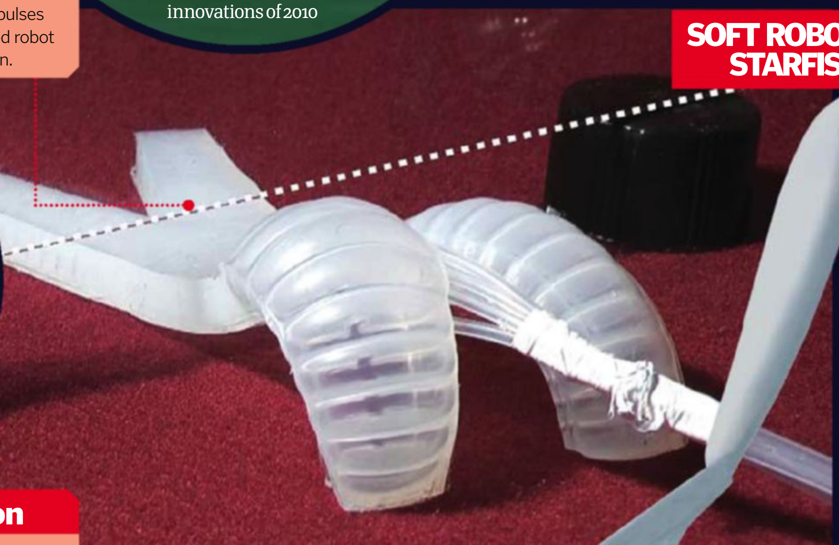
Lifesaving
Emergency Integrated Lifesaving Lanyard (EMILY)

Application: Lifeguard

Status: Operational

When it will replace humans: Currently in use

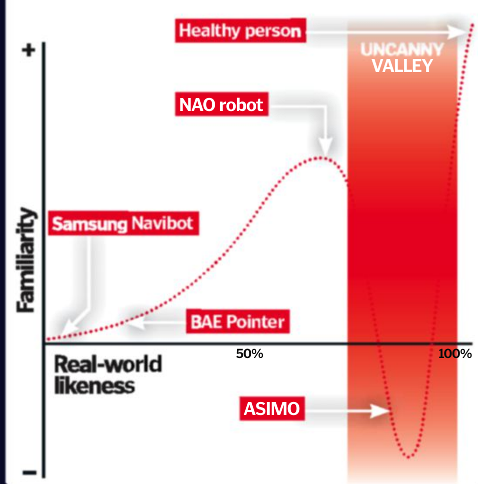
Info: EMILY is a 1.5m (5ft)-long remotely controlled buoy used to rescue swimmers in distress. The buoy can race across the ocean at 39km/h (24mph), enabling swift rescues. It has been advanced with sonar-detection tech which helps it to find and identify distressed swimmers on its own. Once EMILY has reached the swimmer, they can either hang on to the buoy and await a lifeguard, or the buoy can tow them ashore itself.



SOFT ROBOT STARFISH

These soft-bodied robot sea-creatures, whose development is supported by DARPA, could one day be saving lives

UNCANNY VALLEY
Humans have evolved to be repelled by certain things. Aversions to smells, tastes and the way things look are ways of protecting ourselves, eg a dead body produces a strong feeling of discomfort, even if it's much the same as a living one. The 'uncanny valley' theory states we show greater affection towards objects as they become more humanlike, but there comes a point where they get too close, in manner or appearance, triggering repulsion. The key is for robots to be endearing but not too realistic.



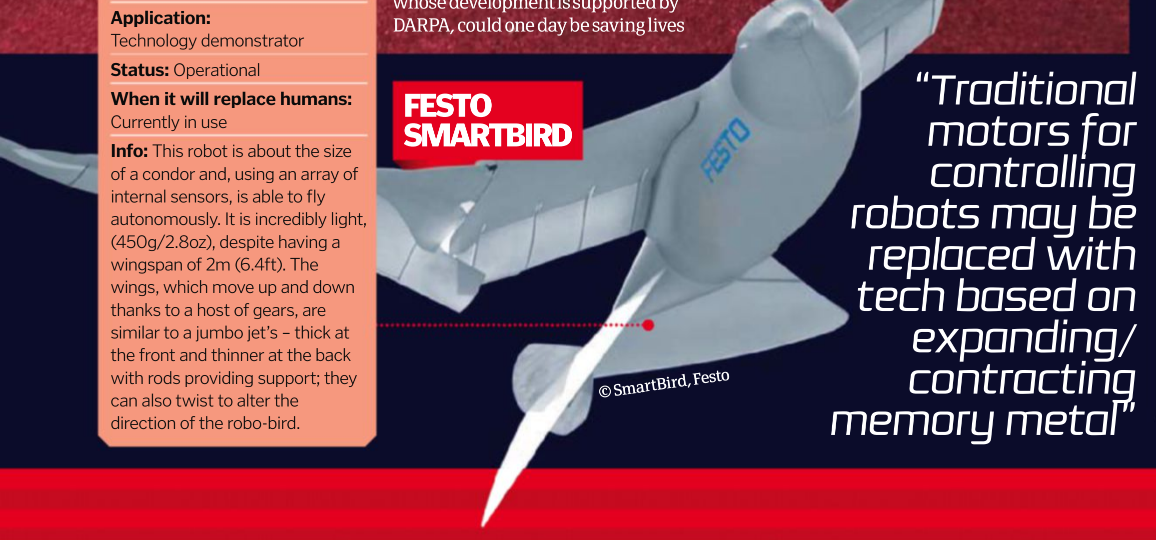
Exploration
Festo SmartBird

Application: Technology demonstrator

Status: Operational

When it will replace humans: Currently in use

Info: This robot is about the size of a condor and, using an array of internal sensors, is able to fly autonomously. It is incredibly light, (450g/2.8oz), despite having a wingspan of 2m (6.4ft). The wings, which move up and down thanks to a host of gears, are similar to a jumbo jet's – thick at the front and thinner at the back with rods providing support; they can also twist to alter the direction of the robo-bird.



FESTO SMARTBIRD

© SmartBird, Festo

"Traditional motors for controlling robots may be replaced with tech based on expanding/ contracting memory metal"

1957
Sputnik I
The very first space robot, though primitive by modern standards, kicked off the Space Race.

1970
Computer control
The Stanford Research Institute develops the first robots that are controlled by computers; these were called Cart and Shakey.

1986
Honda EO
Honda begins building walking humanoid robots, investing 25 years and huge resources into development; this leads on to ASIMO.

1997
RoboCup
The first tournament that aims to have a robot football team one day beating humans is held.

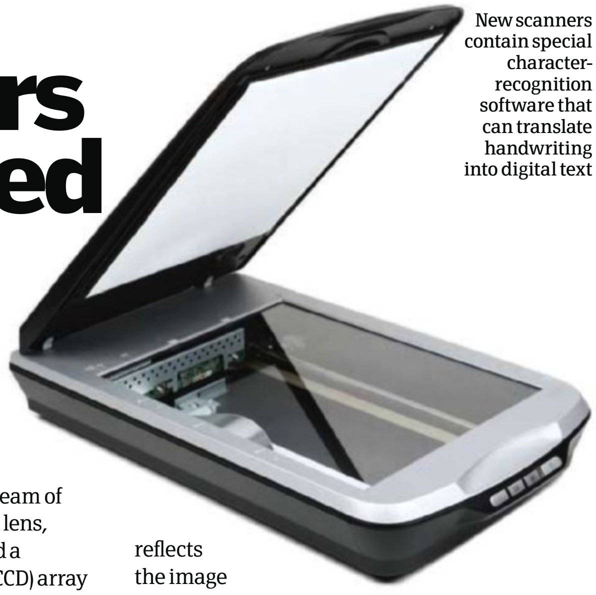
2011
Robonaut 2
NASA launches the second robot astronaut, which can operate tools and assist human astronauts in orbit.

© NASA

2020?
Next-gen robots
The next few years should see robots with quantum computer brains and biomechanical muscles become a reality.

Scanners explained

How do these desktop devices turn printed media into digital files?

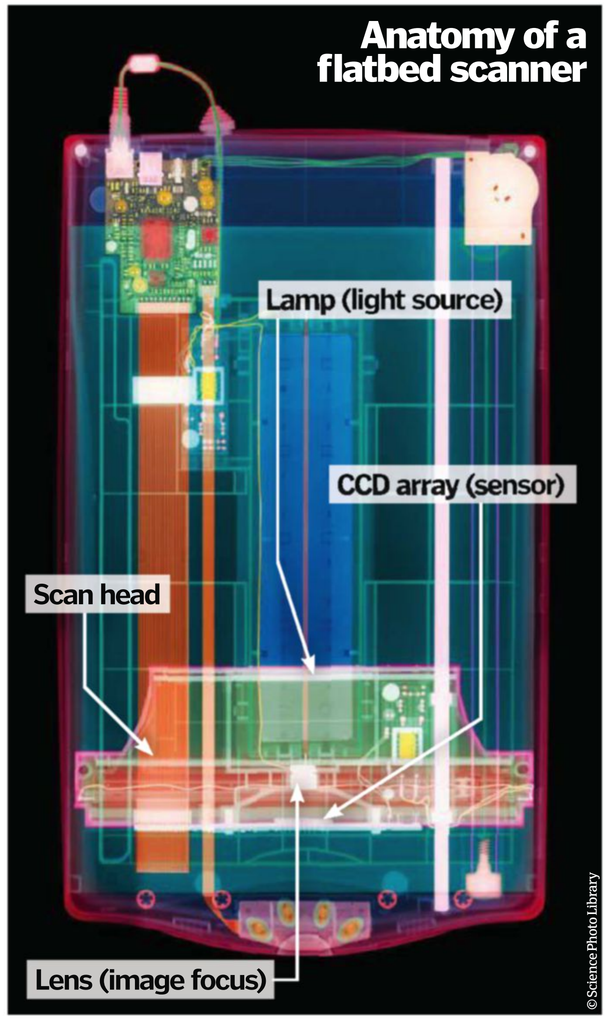


New scanners contain special character-recognition software that can translate handwriting into digital text

Flatbed scanners use a beam of light, mirrors, a focusing lens, filters and a sensor called a charge-coupled device (CCD) array to capture the image of a physical photo or other paper document and convert it into a digital file for use on your computer.

The lamp and mirrors are part of the scan head, which is a sliding mechanism that slowly passes beneath the document to be digitised. Once you have placed the paper face down on the flat glass bed, closed the lid and pressed 'scan', the scan head will begin to pass underneath the page. As it does so, the lamp casts a bright beam of light onto the document above to illuminate it. The first mirror on the scan head – positioned just behind the lamp as it passes by the document – is angled so that it reflects the now-illuminated part of the page onto a second mirror. The second mirror then reflects the image onto a third. Each mirror is slightly concave which means that the image becomes progressively smaller as it is reflected from one mirror to the next in the chain.

At this point the significantly scaled-down picture is reflected from the last mirror through a lens to focus the light through colour filters (usually red, green and blue) and onto the sensor. This sensor (the CCD array) consists of numerous light-sensitive diodes, which convert light energy (photons) into electrical energy (electrons). This produces an electronic, or digital, version of the image, which you can then port to your computer where you can edit, reprint and/or distribute the file.

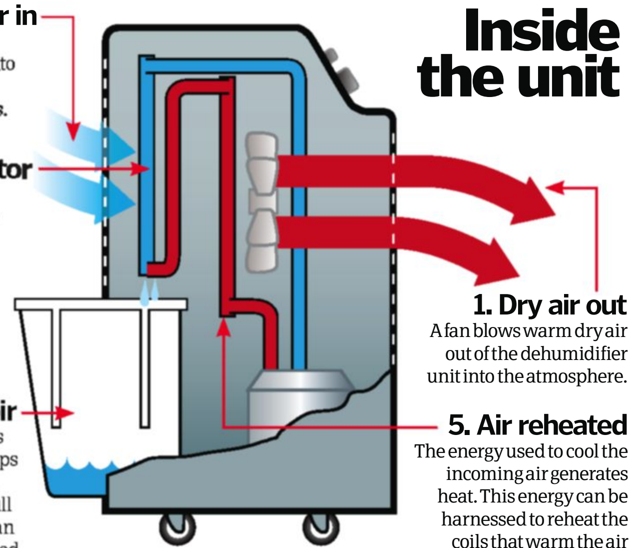


How dehumidifiers work

The household appliance that takes water out of the atmosphere

Dehumidifiers are used to regulate the level of humidity in an environment by removing excess moisture from the air. They work on the principle that when damp air is cooled it loses its ability to hold water; the air's moisture converts to liquid form, which can then be collected and tipped away.

There are three major types of dehumidifier that employ differing techniques: compressor (shown in the image); desiccant, which uses a wheel filled with a drying substance (like salt) to soak up water; and peltier, which uses a cold metal plate.



5 TOP FACTS
EXPERT FLASH TIPS

Change direction
1 If possible, aim the head of the flash up to the ceiling and bounce the light back down onto your subject. This will help to create a much more flattering light.

Soften and disperse
2 Use a diffuser such as tracing paper over the flash head or a specialist Sto-Fen to soften the intensity of the flash and disperse light more evenly around the frame.

Filling in
3 Turn on your camera's flash when the light behind your subject is strong; this will bring them out in the frame by filling in with flash.

Avoid bounce
4 When using flash, ensure there is nothing positioned in front of your subject as this will catch the light first and create a bright distraction in your image.

Know when to use the flash
5 Stationary subjects don't always require flash lighting. The only time you need to use it is when you need to fill in or capture fast-moving subjects.

DID YOU KNOW? *In the late-19th century magnesium flash powder became popular despite the risk of lethal explosions*

How an on-camera flash works

Find out how a six-volt camera generates enough power to fire a flash of 5,000 volts

A flash can create a sudden burst of light in just a fraction of a second. Here you'll discover how an on-camera flash really works and explore the scientific process behind it.

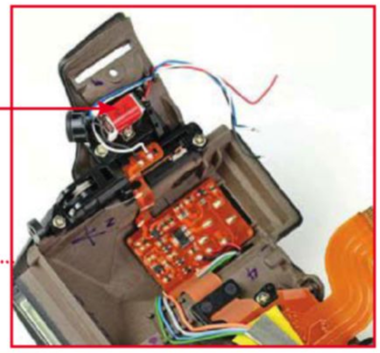
All cameras come with a built-in flash designed to help illuminate a scene when shooting in low light. Varying in type, size and strength, when used correctly a camera flash can enhance your photographs. Flash is ideal for filling in shadows with light, and is also used to freeze motion, ensuring sharper shot results.

Once a compact camera has been switched on it will automatically begin charging the flash capacitor. Used like a battery, the capacitor is capable of storing around 300 volts – just enough to help fire the camera's flash when low light is detected. As a camera's battery is only capable of providing six volts, a transformer is used to convert this directly for storage into a higher voltage of around 300.

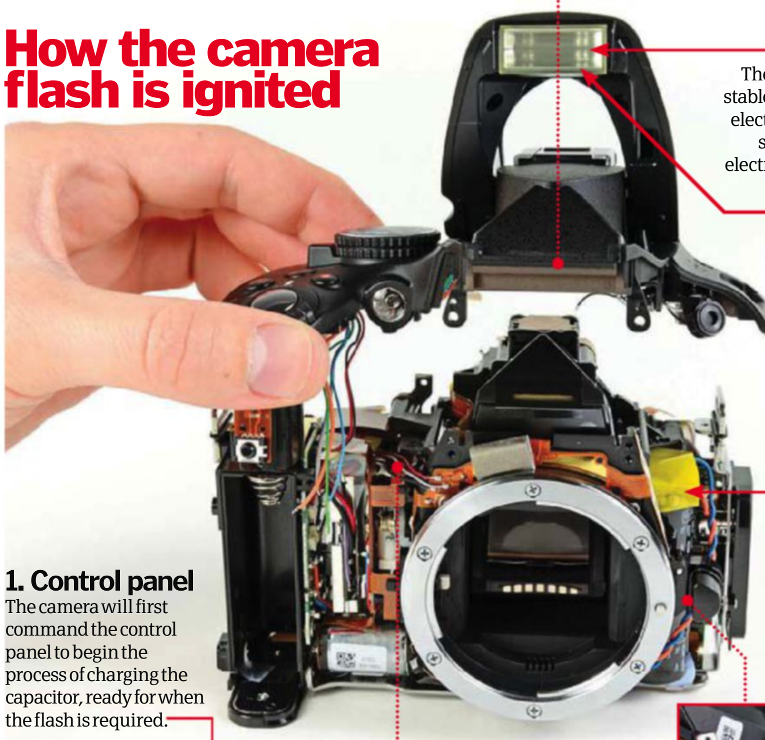
When taking a photograph, the camera determines if there is enough light to correctly expose the image and, depending on your flash settings, will automatically trigger the flash. As the shutter release button is being pressed, some of the 300 volts stored in the capacitor will then run through a trigger coil transformer, converting them further from 300 to 5,000 volts. This high voltage is then conducted by two electrodes, positioned either side of a flashtube, which emits the flash of light. This flashtube is filled with a stable, or noble, gas called xenon. The current emitted by the electrodes excites the xenon atoms, freeing electrons and ionising the gas.

Now the gas is conductive, electrons that remain in the capacitor are released. The flash is generated as the gas atoms in the flashtube collide with the electrons. This flash of light is as bright as over 2,000 lightbulbs in just a fraction of a second, just enough time to capture that shot.

How the camera flash is ignited



4. Trigger coil transformer
When ready to shoot, the trigger coil transformer converts the stored 300V into 5,000V – the amount needed to create a flash of light.

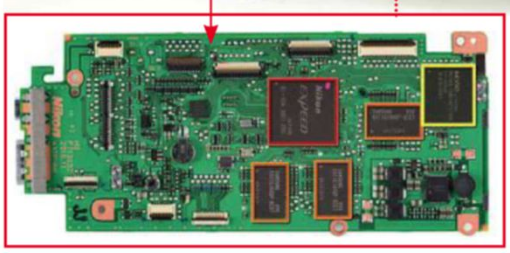


5. Flashtube
The flashtube contains the stable gas xenon and has two electrodes positioned either side designed to conduct electricity and ionise the gas.

6. Creating light
Once ionised, xenon is highly conductive; further electrons are released from the capacitor colliding with gas atoms in the flashtube and creating a bright flash of light.

2. Transforming voltage
To generate enough power to fire the flash, a transformer (not visible) will convert the camera's low 6V into 300V.

1. Control panel
The camera will first command the control panel to begin the process of charging the capacitor, ready for when the flash is required.



3. Storing volts
The capacitor then stores the initial 300V needed to help ignite the flash.

4x © iFixit.com

Flash results

NO FLASH

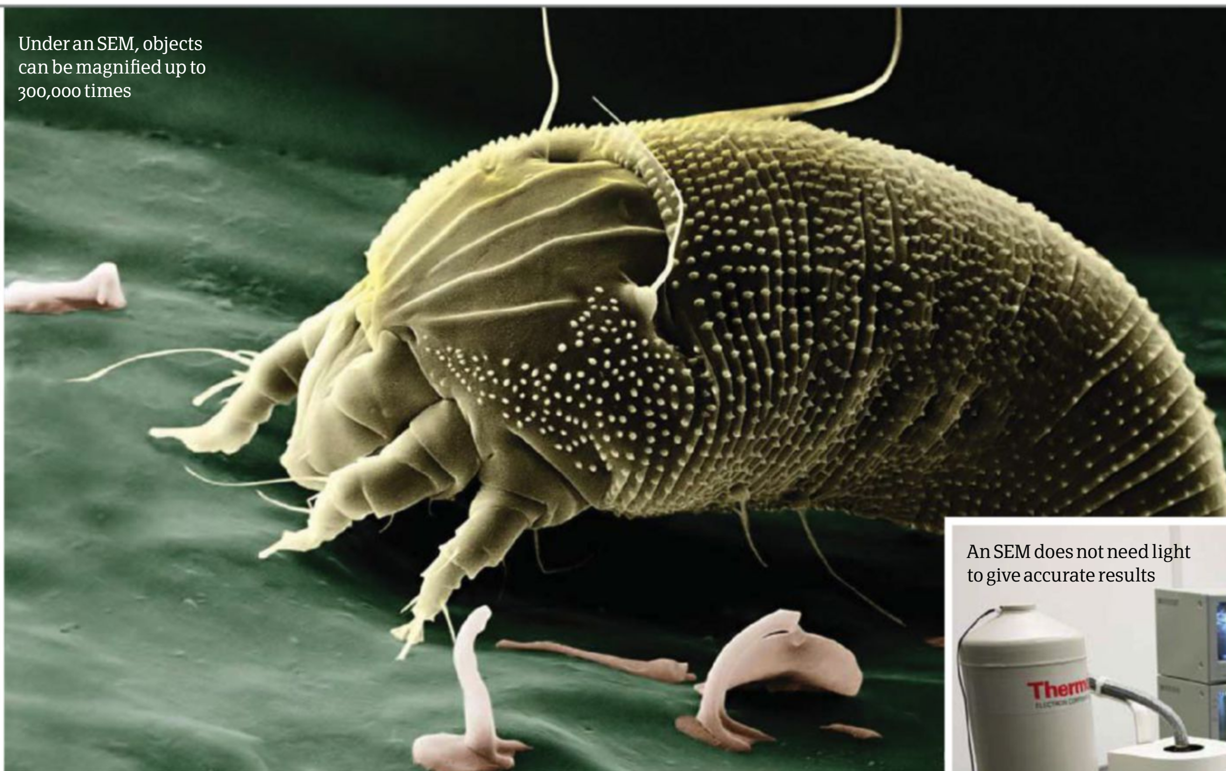
There is a warm orange cast as the model has only been lit by the tungsten room lighting. There is also camera shake present due to slight movements; this could have been avoided had we used the flash.

FLASH ON

The image was taken with a direct on-camera flash. The bright harsh light flattens the image and creates strong contrast and shadows. Not flattering to light an entire scene, on-camera flash is best used to fill in light on bright days.

BOUNCED FLASH

This image was taken using an external flash light (speedlight); the flash head was rotated and the light was bounced off a white ceiling. This technique creates a softer, more flattering light for portraiture.



Under an SEM, objects can be magnified up to 300,000 times

Some samples are coated in gold so that they can be 'seen' by the SEM

© Peter Halasz

An SEM does not need light to give accurate results

© Daniel Schwen

Scanning electron microscopes

We put these marvellous magnification machines under the microscope

When the scanning electron microscope (SEM) was unveiled in 1935, its reception was lukewarm at best. Despite the potential to magnify objects up to 300,000 times, scientists struggled to see a commercial use for the bulky and expensive machines. However, their application was vastly underestimated, and today more than 50,000 are in use worldwide, largely for industrial purposes. SEMs have a variety of modern-day uses, from forensics to microchip production and insect observation.

SEMs have many advantages over other methods of magnification such as optical microscopes. For example, they do not rely on light for their images, which is a major drawback of their optical counterparts. Light is unpredictable as it can diffract and bend around objects, potentially making observations very difficult. As their name suggests, scanning electron microscopes instead rely on the release of electrons to make observations.

Inside a scanning electron microscope's casing are an electron gun, several coils, and condensing lenses that work together to observe a target sample in super-fine detail. The core principle of an SEM is that it uses a 'tracing' technique to produce a replicated 3D image of the original sample being studied. It does this by scanning its electron beam over an object and measuring the electrons given off at a particular point. Using this process it can create a 'trace' of the object, and output an amplified image to a display. This is made possible by scanning coils, which create a magnetic field that moves the beam across the surface of the sample. The smaller the area the beam sweeps across the larger the magnification will be, and vice versa.

One of the most important aspects of using an SEM is preparing a sample for observation and ensuring that there is nothing that could hinder the final image. Samples must be thoroughly cleaned to get rid of any dust, debris or alien material not native to the sample that could skew results. The sample must also be able to conduct electricity. If it can't, electrons will not leave its surface when struck by the beam. Objects that aren't already conductive will be coated in a fine layer of gold or platinum in a process known as 'sputter coating'. This also prevents the sample becoming damaged by the beam during observation.

DID YOU KNOW?

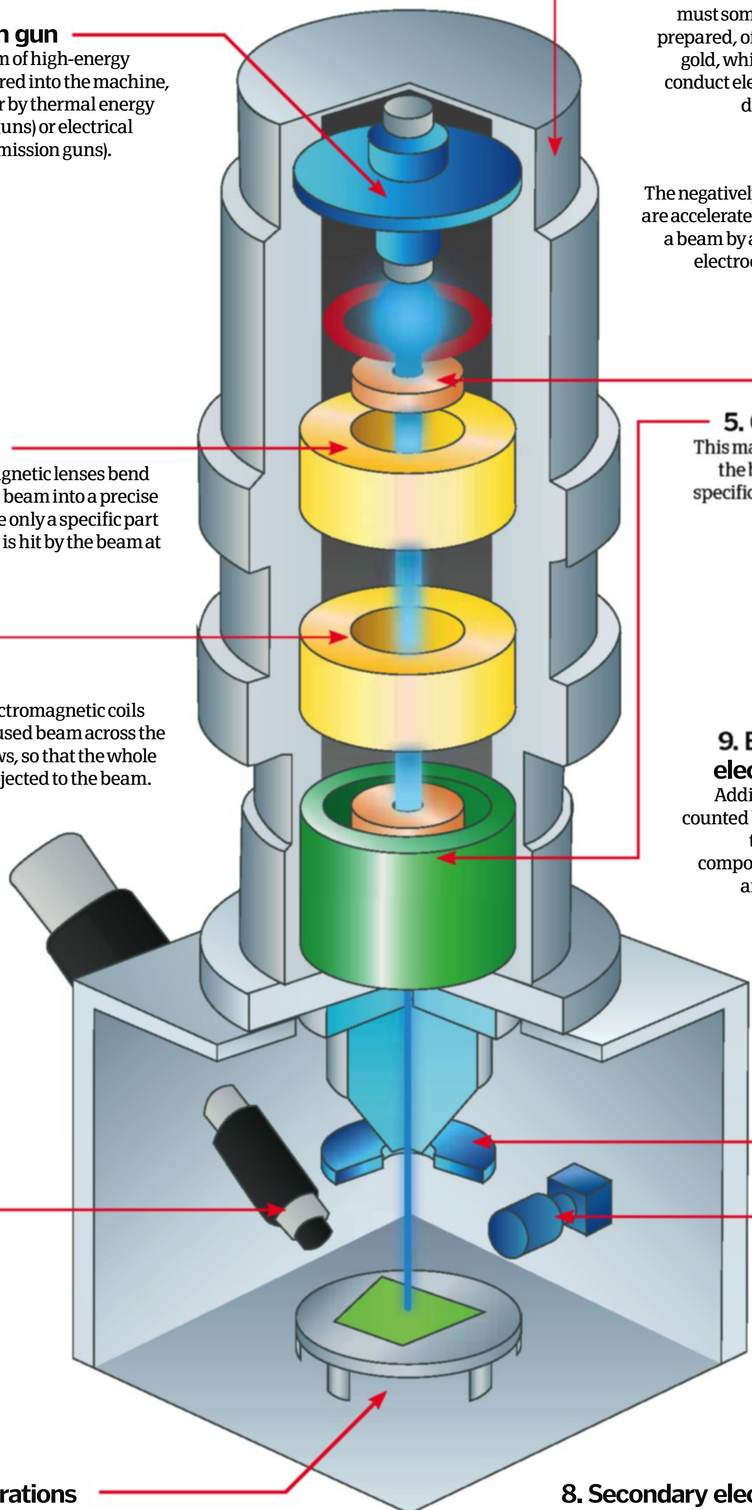
Colouring in

In the past, scanning electron microscopes, like optical microscopes, were unable to produce images in colour without postproduction. However, modern SEMs can assign colours to different elements and thus glean a colour image of a magnified shot.

DID YOU KNOW? *In 1993 an SEM helped convict a man of murder by linking him to traces of iron at a crime scene*

Inside a scanning electron microscope

How is an SEM able to produce highly magnified images of a sample?



1. Electron gun
A steady beam of high-energy electrons is fired into the machine, created either by thermal energy (thermionic guns) or electrical fields (field-emission guns).

2. Vacuum
The inside of the microscope is a vacuum. For a sample to survive it must sometimes be specially prepared, often being coated in gold, which also enables it to conduct electricity and release detectable electrons.

3. Anode
The negatively charged electrons are accelerated and confined into a beam by a positively charged electrode, called an anode.

4. Lenses
A series of magnetic lenses bend and focus the beam into a precise spot to ensure only a specific part of the sample is hit by the beam at any one time.

5. Objective lens
This magnetic lens focuses the beam further onto a specific area of the sample.

6. Sweep
Scanning electromagnetic coils move the focused beam across the sample in rows, so that the whole sample is subjected to the beam.

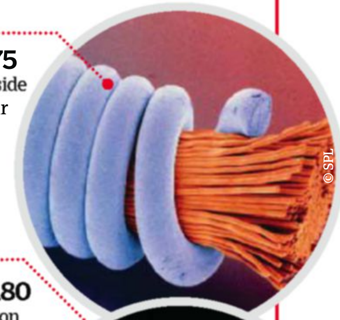
7. Bad vibrations
The sample is placed on a stage inside a chamber of the machine. This must be kept extremely still as SEMs are very sensitive to vibrations.

8. Secondary electron detector
As the beam strikes the surface of the sample it knocks electrons loose. By counting the number of electrons released, a detector can produce a magnified image of the sample.

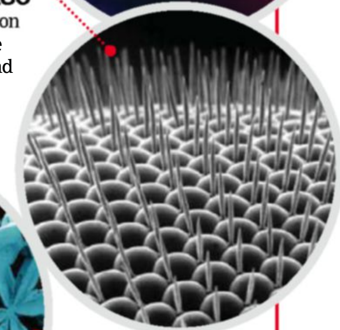
9. Backscattered electron detector
Additional electrons are counted by another detector that determines the composition of the sample and also deduces the elements present.

Under the microscope

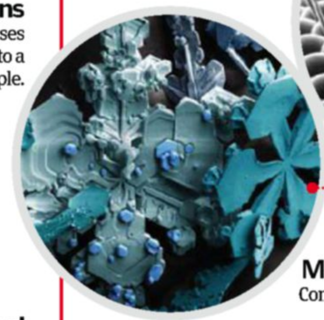
Get up close and personal with these objects and insects



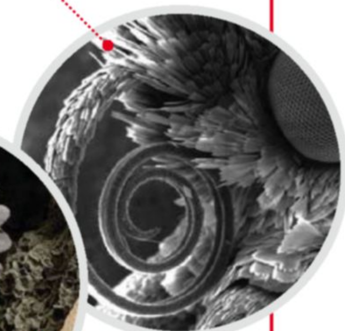
Guitar string
Magnification: x75
Here, you can see the inside of a 'super-wound' guitar string under a scanning electron microscope.



Fly eye
Magnification: x180
This is a scanning electron microscope image of the drosophilidae compound eye of a fruit fly.

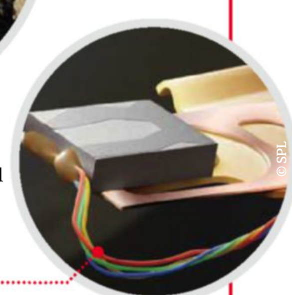


Snowflake
Magnification: x100
Computer-generated colours have been used on this snowflake to highlight its crystalline structure.



Moth
Magnification: x75
In this close-up view of a pyralidae moth you can see the side of its head, including its compound eye and its proboscis.

Peacock mite
Magnification: x260
Here's a pest commonly found in the tropics known as a peacock mite, imaged here on a tea stem.



Computer hard disk
Magnification: x20
This is the read and write electromagnetic device inside a computer's hard disk. The electromagnet (grey block) is magnetised to store data.

Cashless shopping

How to use your mobile phone as an e-wallet

If you already use a smartcard to pay for your morning latte using Visa's payWave or are based in London and use your Oyster Card to negotiate the Underground, you're already familiar with near-field communication (or NFC). When you wave your card at the reader attached to a till etc, your bill is instantly paid as your card has electronic money stored in its smart chip. NFC places that smart chip into your mobile phone.

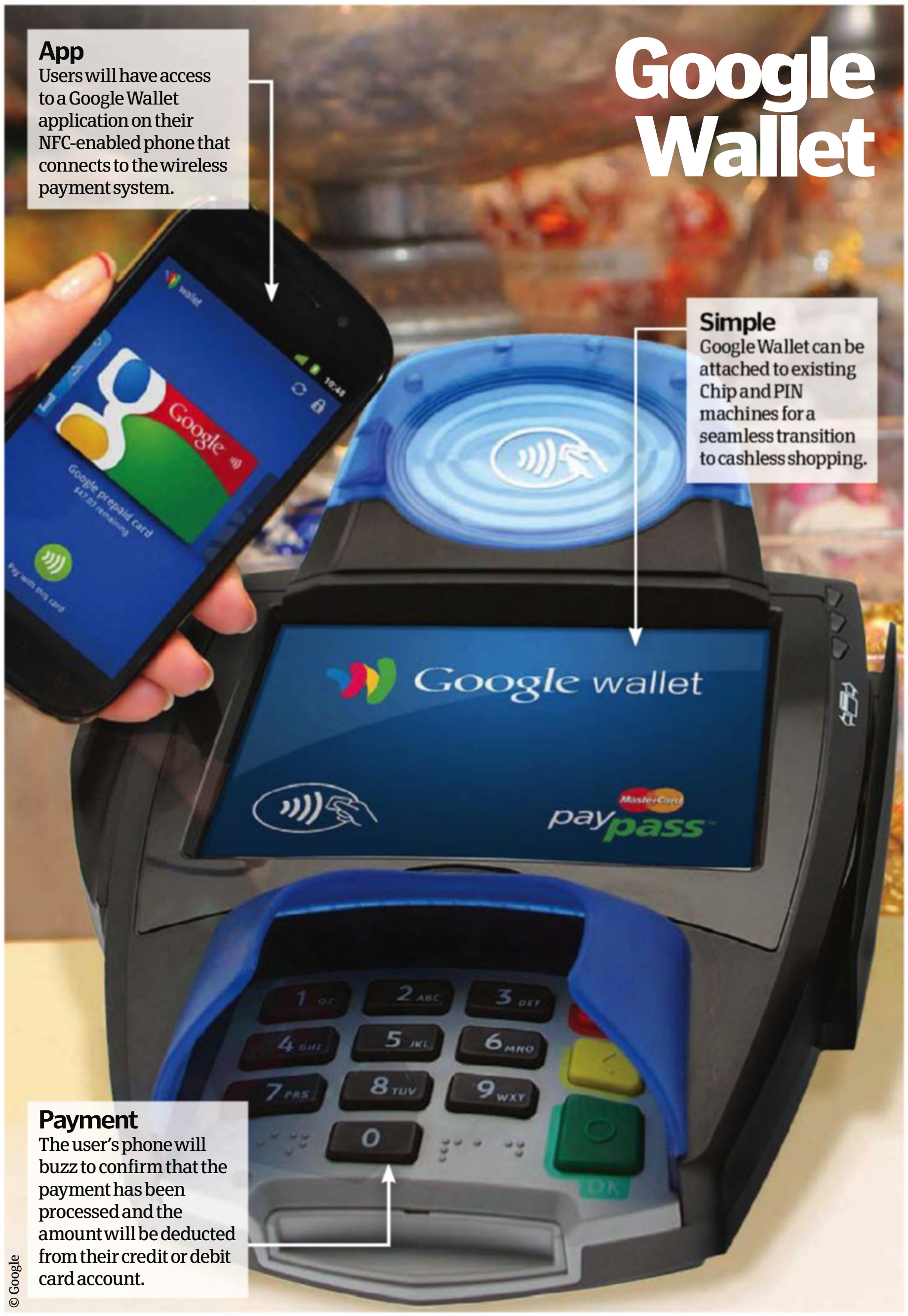
The technology works via short-range (20cm/7.9in) wireless communications at 13.56MHz that are similar to radio frequency identification (RFID) chips that form the foundation of all NFC devices. With an NFC-enabled mobile phone, the RFID chip works in a similar way to Bluetooth in that your phone makes a wireless connection with the till to pay your bill. According to Juniper Research, one in five smartphones will have NFC built in by 2014 with half a billion people using NFC just a year later.

At the moment only a handful of smartphones have NFC built into them that Europeans can get their hands on. In the UK, Orange has teamed up with Barclays bank to offer the first off-the-shelf NFC phone you can buy today that comes with its Quick Tap service. Google Android phones also look set to have NFC built in. However, interestingly, Apple's iPhone 4S does not include the technology in its latest handset.

Quick Tap is the first contactless mobile phone service. Based on the Samsung Tocco Lite handset, you'll need an account with Barclays and Orange to use the service that allows you to make contactless purchases of up to £15 from stores such as EAT, Subway and Pret A Manger.


Google believes NFC technology, such as its Wallet app, is set to revolutionise how we pay for things

© Google



© Google

Cashless history

1950
Diners Club card invented
So that people could eat without cash, Diners Club founder Frank McNamara developed the first credit card for his customers.

1958
First credit card issued
Seeing the success of the Diners Club card, American Express and Bank of America both issued their first credit cards.

1973
Payments become electronic
BASE I, implemented in 1973, is the first electronic payment authorisation system, cutting average authorisation times from five minutes to 56 seconds.

1988
First Switch transactions
October 1988 saw the first Switch transaction take place. It was supported by Midland, RBS and NatWest banks.

1988
SuperSmart card tested
The Visa network tests the world's first smartcard in Japan that contains a multifunctional chip.

1995
Mondex e-money trial goes ahead
Mondex begins testing the UK's first smartcard-based e-money system in Swindon on 3 July.

PAST

1. Chip and PIN
Chip and PIN trials began in Northampton in the UK back in 2003. Using smartcard technology, the system laid down the foundations for NFC.

PRESENT

© Orange

2. Quick Tap
The latest NFC contactless payment system is from Orange and Barclays. Using a specialised Samsung smartphone you can make payments of up to £15.

FUTURE

3. NFC e-wallets
Special NFC smartphones will eventually be replaced with NFC SIMs that will be able to convert any smartphone into an NFC e-wallet.

DID YOU KNOW? *Two-thirds of the 23 billion cash transactions in 2010 were under £10, ideal for NFC systems*

Wave to pay

Load your mobile account
You can transfer money from your account on to your NFC device. In the case of Quick Tap, a maximum of £100 can be loaded.

© Orange

Make your choice
At the moment contactless NFC payments are for low-cost items. You can only make purchases up to £15 with the Quick Tap service from Orange and Barclays.

© Orange

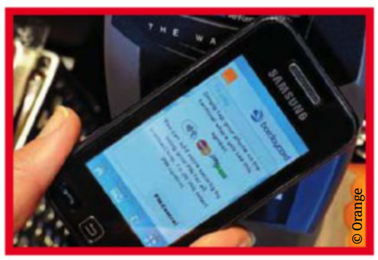
Get an NFC-enabled device
The Barclaycard and Orange Quick Tap system uses the Samsung Tocco Lite phone that comes with the contactless payment SIM.

The connection is made
The till scans your items. You can then use the app on your phone to make a payment. Bring your smartphone close to the NFC reader to complete the transaction.

Check your mobile operator
To use the Quick Tap service, for instance, you'll need to be an Orange customer. Contactless payment SIMs for other networks will also be available soon.

Wireless handshake
Your phone and the reader make a wireless connection that is similar to how Bluetooth connects a headset to a smartphone.

© Orange



© Orange

Security checks
The RFID chip in your phone checks that you have the funds. You can also doubly protect your purchase with a PIN number if you want.

Open a compatible bank account
At the moment there is no interoperability between the existing contactless systems. You'll need a bank account that offers contactless payment services.

Contactless crime
The RFID chip that NFC uses is encrypted using AES standards to ensure that your money is safe. NFC phones may also have biometric security built in. The Motorola Atrix 4G, for instance, has a fingerprint reader to protect the handset from unauthorised use.

Smartphones already have what is called a 'secure element' that can be used by NFC to ensure that stored data is encrypted. With NFC SIMs, an ETSI-compliant single wire protocol (or SWP) interface that is used by the NFC modem when it connects to the retailer's till is responsible for security. And as the wireless connection is always encrypted, your money is safe. Lost NFC phones should be treated the same as a lost credit or debit card. If your NFC phone is used illegally, the banks treat these purchases as fraud, which means you should get your money back just as if your credit card was used illegally.

2003
Chip and PIN
Chip and PIN trials begin in Northampton, which heralds a universal move to signature-free electronic payments.

2004
The NFC Forum is established
As a joint venture between Philips, Nokia and Sony, the NFC Forum seeks to promote standards with its NFC-enabled chipsets.

2006
First NFC-enabled mobile phone released
Nokia becomes the first major mobile phone manufacturer to release an NFC-enabled handset – the 6131.

2007
Europe's first contactless payment card
Visa introduces Visa payWave – the new way to pay for low-value purchases in less than a second.

2011
Google Wallet announced
Google, Citi, MasterCard, First Data and Sprint announce and demonstrate Google Wallet, an app that will turn your phone into a wallet.

2011
Quick Tap launched
Orange and Barclaycard release details of the NFC-based payment system that allows contactless purchases of less than £15 to be made.

How voice recognition works

Discover the software that's capable of interpreting the spoken word

We are beginning to encounter voice-recognition software in all walks of life, from customer-service operators to internet searches, with advances in technology making it much more accurate than it has ever been in the past.

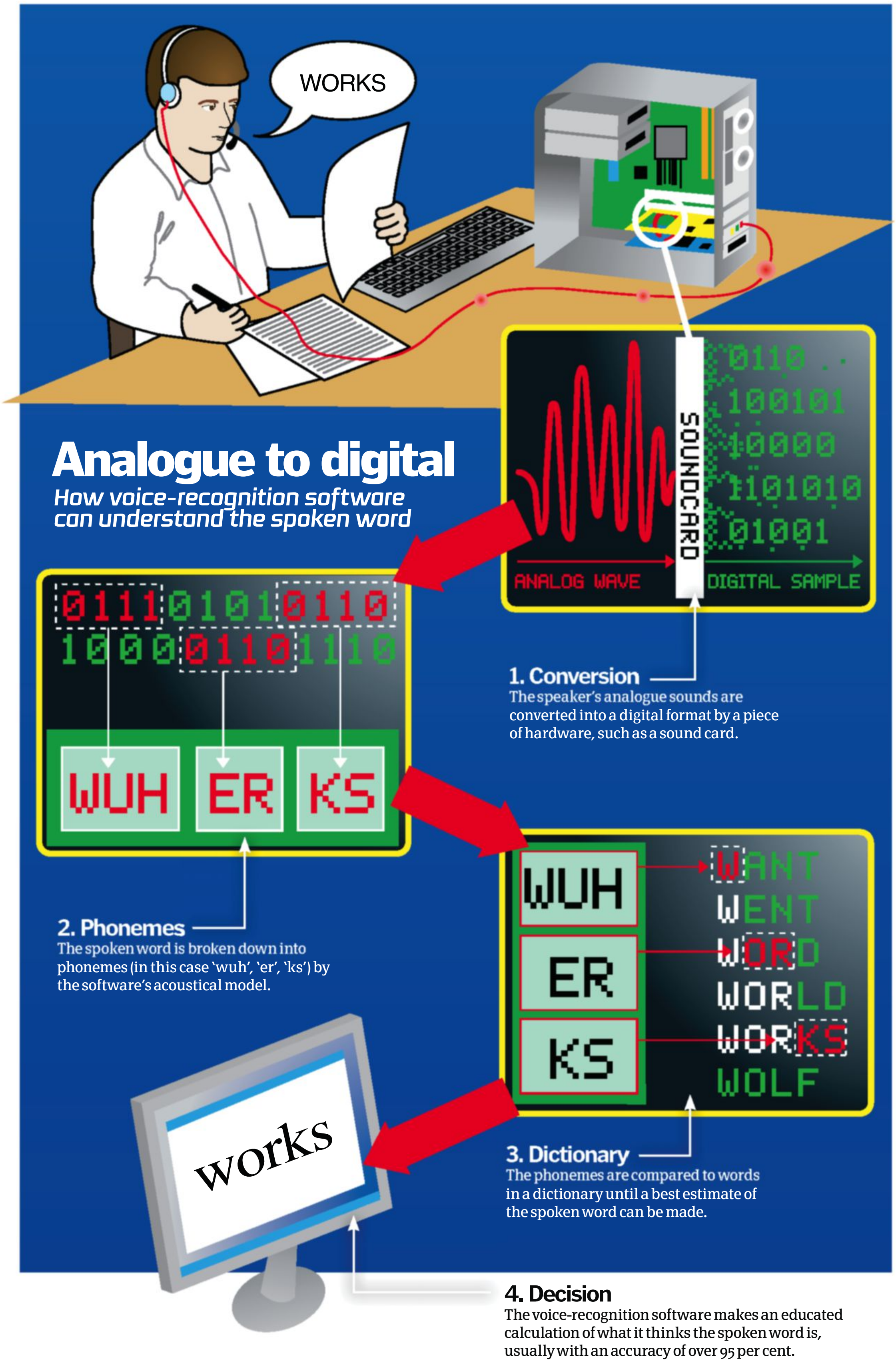
Many of us are already familiar with the fact that when we speak, the sound that we produce causes the air to vibrate. A voice-recognition program contains an analogue-to-digital converter (ADC) that, when spoken to (by telephone, microphone or otherwise), is able to change the analogue sound wave into digital data, specifically wavelike electrical signals.

Speech-recognition software analyses the separate phonemes of this digital signal, which are the fundamental components (specific sounds, such as 'huh' and 'ah') of speech, and then subsequently puts them back together as full words.

Many words sound rather similar, however, so the software uses a system known as trigram analysis in order to check a database of three-word clusters. This system calculates the probability that two words will be followed by the given third word. For example, if you were to say "Where am", the next word could be recognised as the pronoun "I" rather than "eye", both of which sound the same but, of course, have very different meanings.

Ultimately this system enables the software to deduce the spoken word or phrase and consequently produce a response accordingly, whether this is talking back to the speaker or perhaps directing them through a series of menus.

> *"A voice-recognition program can change analogue sound waves into digital data"*



5 TOP FACTS ELECTRICITY GETS SMART

Behavioural change
1 Once you have a meter installed you quickly become sensitive to the amount of electricity you are using. Energy paranoia can reduce energy usage, which in turn can cut carbon emissions.

Business matters
2 After installing smart meters the World Museum in Liverpool saved huge levels of CO_2 and £36,000 per year, giving a payback on the initial stake in just over seven months.

Every home will have one
3 It's thought that every home in the UK should be fitted with a smart meter by 2020. This is estimated will save consumers between £2.5-3.6 billion over the next two decades.

Go mobile
4 In a bid to educate everyone about energy usage, many of the main suppliers now have iPhone and iPad apps that allow you to closely monitor your electricity consumption.

Smart homes
5 These meters are only the first step towards a smart home with systems like AlertMe (**www.alertme.com**) arriving where you'll be able to monitor energy usage no matter where you are.

DID YOU KNOW? *The military uses many types of flare, sometimes as a countermeasure against heat-seeking missiles*

Electricity smart meters explained

Keep an eye on how much power you're using with one of these clever gauges

Electricity meters come in two varieties: the DIY approach or the fixed meter that is installed by your electricity supplier. Using the DIY approach the meter monitors your electricity usage via a sensor that clips onto the main electricity cable usually located in your meter cupboard. This sensor has a wireless transmitter that sends your electricity usage data to the display unit, which can be positioned anywhere in your home.

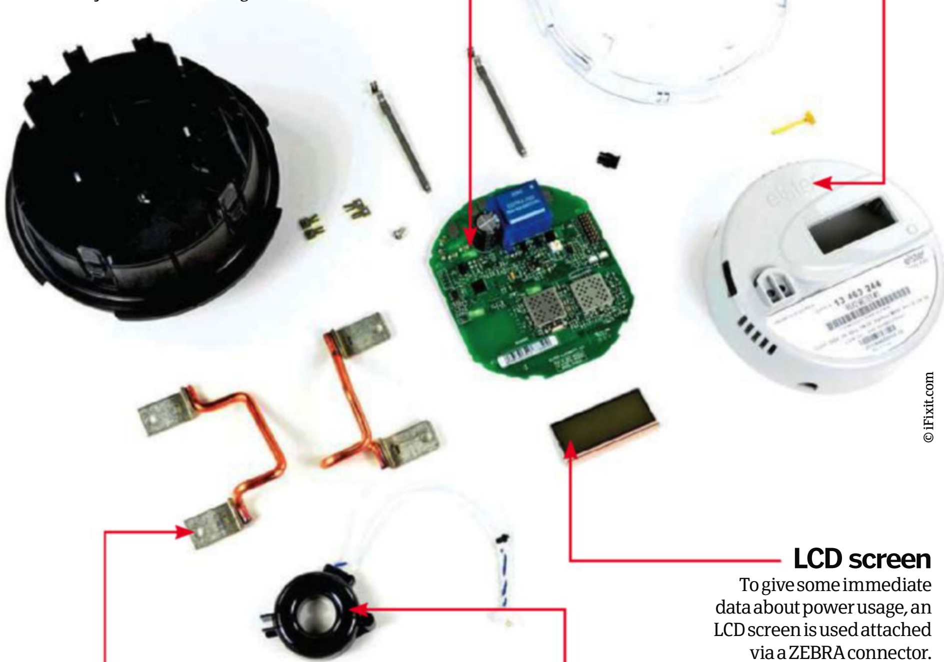
Meters directly connected to your electricity supply operate in much the same way as the DIY variety, but they are wired directly into your power supply. Most meters use radio frequency (RF) transmitters in the 900MHz ISM (industrial, scientific and medical) band that is reserved for special radio transmissions as well as systems like Bluetooth, though some utilise the 2.4GHz and 5.8GHz bands. The RF enables your reading to be sent to the supplier.

Smart meters send your readings to your electricity company in about 45 seconds, once a day. Some meters can also be read with portable handheld devices, but you no longer have to be home when a reading is due.

Inside the REX2 Smart Meter

Security sealed
Tampering with electricity meters is illegal. The meter's outer case has a security seal that must not be broken for the device to stay valid.

Main integrated circuits
The meter consists of a system chip, LCD driver and an amplifier IC that, together, allow the meter to read and transmit your electrical usage.



© iFixit.com

LCD screen
To give some immediate data about power usage, an LCD screen is used attached via a ZEBRA connector.

Power supply
The smart meter needs a power supply. The thick copper wires enable the meter to be plugged directly into your home's mains.

Current transformer
The meter can't directly measure electrical usage; instead it uses a current transformer that sends power consumption information to the meter's electronics.

The same mechanism that is used in traditional firearms was only slightly adapted for the flare gun

© Orion

How do flare guns work?

Discover the mechanism that makes this lifesaving device go off

A flare gun works in the same way as any traditional firearm with one key difference: it must ignite its projectile and propel it high into the sky. Generally credited to Edward Very (1847-1910), the first gun that could fire a flare was tested by the American Navy back in 1882.

When the trigger of a flare gun is pulled, a chain of events begins. First, the flare's propellant is ignited as the gun's hammer strikes the detonator cap. The signal is then pushed out of the gun's barrel through deflagration, which is a subsonic combustion process where an intense burning of gases in a small space generates great pressure.

The short time it takes to ignite the propellant is enough for the flare to also be lit. These objects burn so brightly because they contain magnesium, an element also used in fireworks. Other chemical additives can produce varying colours. In some cases, the flare will also have an inbuilt parachute (most commonly for military use) that prolongs its fall to Earth and extends the average 40-second period that a flare will typically burn for.

In 1949 it was boldly predicted that 'Computers in the future may weigh no more than 1.5 tons.' To the author, such a 'lightweight' machine would be almost inconceivable. The only computer around at that time was the ENIAC, a Goliath calculating machine that weighed a colossal 27 tonnes (30 tons) and measured 30 metres (98 feet) in length. The brains of the machine consisted of 17,468 vacuum tubes, lightbulb-like plugs that acted as transistors, switching the electrical current on and off to correspond with the 1s and 0s of binary code.

Imagine if you could travel back in time and present the author of that article with an iPhone. Inside the iPhone is a circuit board mounted with over a dozen microprocessors, each tens of thousands of times more powerful than the 27-tonne ENIAC, and each no larger than a fingernail. The iPhone sill relies on transistors to switch between 1s and 0s, but instead of using 17,468 hot and power-hungry vacuum tubes, the iPhone harnesses the collective computing power of hundreds of millions, even billions of infinitesimally small transistors mounted on a miracle we call the microchip. One and a half tons? Try 137 grams (4.8 ounces).

"The iPhone harnesses billions of transistors mounted on a microchip"

5 TOP FACTS MICROCHIPS

Lightning switches

1 The nanoscale transistors found on modern microchips can be turned on and off at an unthinkable rate of over 100 billion times a second.

Too many zeros

2 With hundreds of millions of transistors on each chip, Intel estimates that it ships 10,000,000,000,000,000,000 (that's 10 quintillion) transistors every year.

Moore's challenge

3 Moore's Law isn't a 'fact' like Newton's Laws of Motion. It's merely a prediction that transistor capacity will double roughly every two years; one that has held true for 46 years.

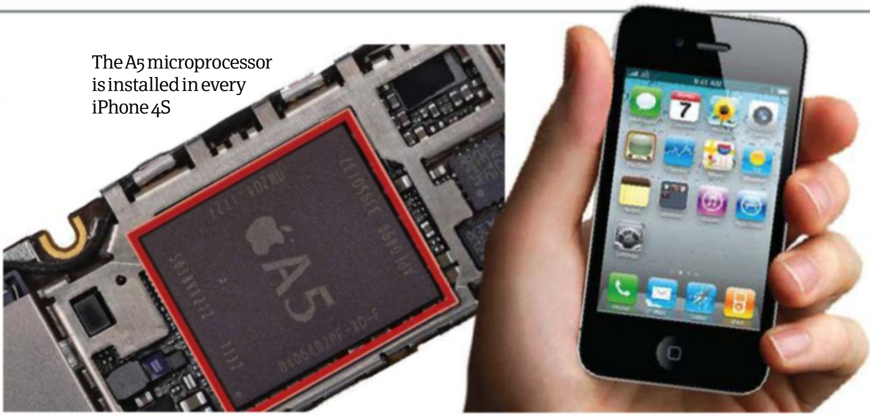
Nano transistors

4 The latest chip-making technology from Intel produces transistors that are so small that an amazing 30 million of them could fit on the head of a pin.

Endless supply

5 The versatile material upon which the microchip is constructed, silicon is the second-most abundant element in the Earth's crust. It is beaten only by oxygen.

DID YOU KNOW? *Early computers ran on vacuum tubes. ENIAC, the first digital computer, required nearly 18,000 of these tubes*


The A5 microprocessor is installed in every iPhone 4S

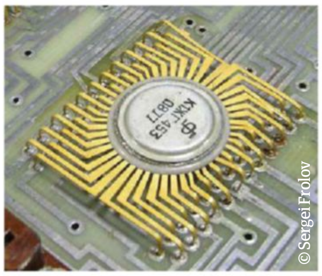

A modern, flexible electronic circuit above a traditional wiring loom

© Science Photo Library

History of the microchip

The history of the microchip starts with the transistor in the mid-20th century. A transistor is a device that amplifies a signal or powers a switch with nothing more than a jolt of electrical current. The first transistors were made from vacuum tubes and looked like small lightbulbs. Early computer pioneers discovered that transistors could be used as switches to run simple logic programs. As computer programs became more and more complicated, engineers required more transistors.

But vacuum tubes failed often, produced too much heat and required lots of energy to run. In 1947, three researchers at Bell Labs in the USA proved that a transistor could be built from the semiconducting element germanium. These tiny transistors could be soldered onto circuit boards to run handheld radios and calculators. But to build even smaller, more powerful devices, engineers needed to pack more transistors into a smaller area. In 1958, Robert Noyce at Fairchild Semiconductor and Jack Kilby at Texas Instruments independently discovered that an entire circuit board could be stamped from thin layers of silicon, a cousin of germanium. Every generation of microchip packs more and more transistors per square centimetre. Dual-core Intel processors include over a billion transistors.


An early USSR-made integrated circuit

© Sergei Frolov

"Inside the iPhone is a circuit board mounted with over a dozen microprocessors, each tens of thousands of times more powerful than the 27-tonne ENIAC"

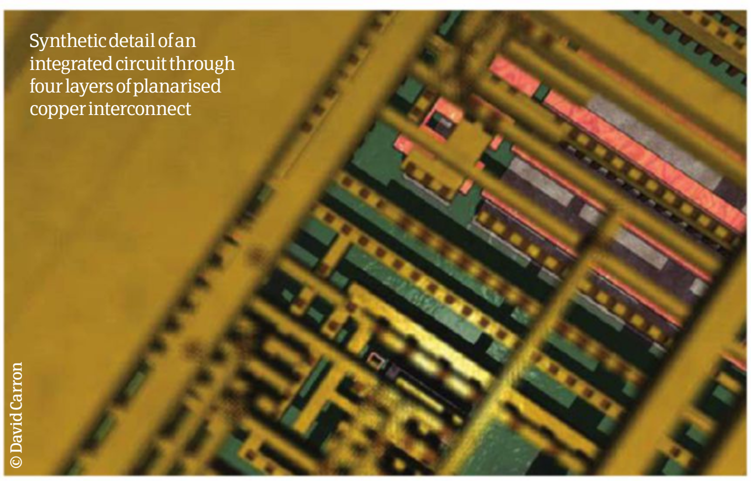
The microchip is nothing short of an engineering marvel. Since the first silicon-based transistors began to replace vacuum tubes in the early Fifties, electrical engineers have dreamed up ingenious new ways to shrink the components of an electrical circuit (transistors, capacitors, resistors, diodes, etc) into a wafer-thin package. The game-changing breakthrough was the 1958 invention of the integrated circuit, the mother of all modern microchips. Prior to 1958, electronics manufacturers had to hand-solder and wire every component on their increasingly small circuit boards. With the integrated circuit, every component of the circuit is cut from the same silicon.

But even the breakthrough of the all-in-one circuit doesn't explain how modern chipmakers can mass-produce minuscule squares holding hundreds of millions of transistors. To do that, we must enter the 'fab'. Fabs are the multi-billion-dollar facilities that house the clean rooms in which microchips are born. Clean rooms are the most tightly controlled environments in the world. When you are fabricating materials that are 45 billionths of a metre wide, the slightest surge of static electricity or microscopic dust speck could ruin everything. Fab technicians dress in head-to-toe 'bunny suits' to lower the risk of contamination.

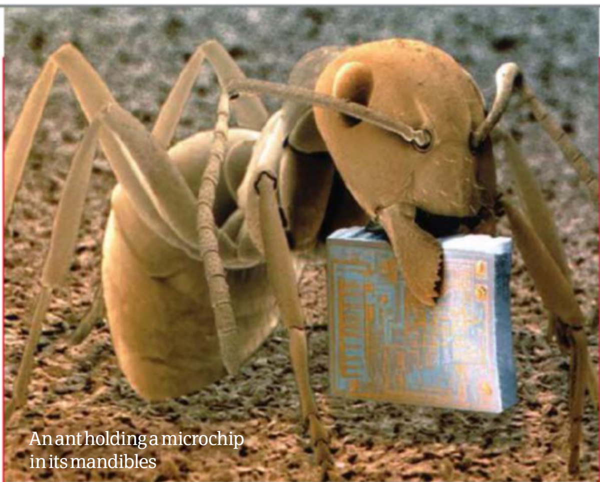
To understand how microchips are made, think of building a house with a child's Lego set. But instead of building each wall one at a time, do it layer by layer. Start with a flat square of Lego pieces that traces the outline of the four walls. Now add the next layer of Lego bricks, and another, building upward until you have four full walls.

Microchips are fabricated using the same layering technique – up to 40 layers for the most complex chips. The first layer is a thick (1mm/0.04in) base of ultra-pure, polished silicon. Silicon is the material of choice because of its semiconducting properties, which means it can act as a conductor or insulator of electricity depending on the job it needs to do. Engineers can change the conductive property of silicon by 'doping' it with different chemical impurities. Other layers are silicon oxide insulators, photoresistant coatings and metal (copper and tungsten) for the wire connections.

Using a process called photolithography, chipmakers can imprint precise blueprints onto each layer and etch away the unnecessary sections with chemical solvents. Intensely focused lasers enable chipmakers to trace lines to an accuracy of 5nm (one nanometre is four silicon atoms wide). Each chip is subjected to multiple rounds of testing before it is installed in your mobile, digital camera, car, toothbrush or your little niece's talking doll. Indeed, there is no corner of modern life that hasn't been fundamentally changed by the invention of the microchip. And with news of molecular transistors and quantum-scale circuits, the future is looking set to surpass even our wildest predictions.


Synthetic detail of an integrated circuit through four layers of planarised copper interconnect

© David Carron

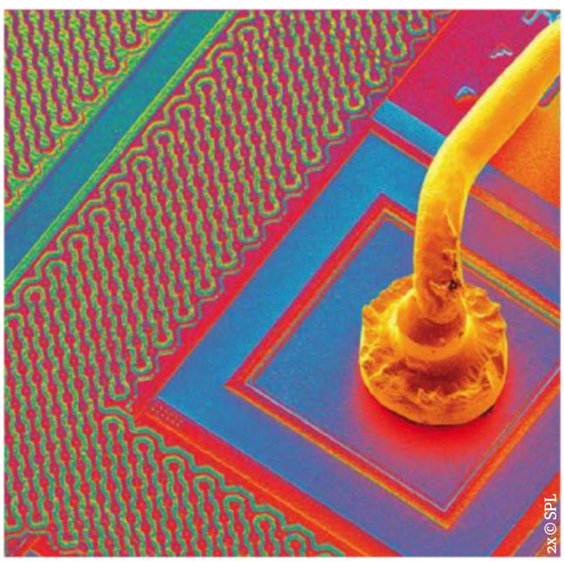


An ant holding a microchip in its mandibles

From micro to nano

When Intel released its first microprocessor in 1971, it held 2,300 transistors, a mindblowing quantity for a chip the size of a fingernail. Six years earlier, Gordon Moore, one of the founders of Intel, published a paper in which he predicted that the number of transistors incorporated into a chip would double every 18 to 24 months. Moore's Law, as it's now known, has remained true for over 40 years, challenging generations of engineers to build impossibly small, incredibly powerful microchips.

Intel's latest chipsets hold hundreds of millions of transistors. To cram so many transistors into such a small space, engineers must work at the nanoscale (billionth of a metre). A human hair is 100,000nm in diameter, while the smallest transistors in production boast widths of only 22nm! The manufacture of nanoscale components relies on breakthroughs in photolithography, the use of ultraviolet light rays to etch super-precise patterns onto photoresistant film. As chip components approach the atomic scale, however, the rules of physics change. To extend Moore's Law, engineers will need to develop new materials and designs that resist quantum tunnelling, the tendency for electrons to leak through very thin barriers.



2X © SPL

A coloured SEM photo of one of an integrated circuit's micro-wires

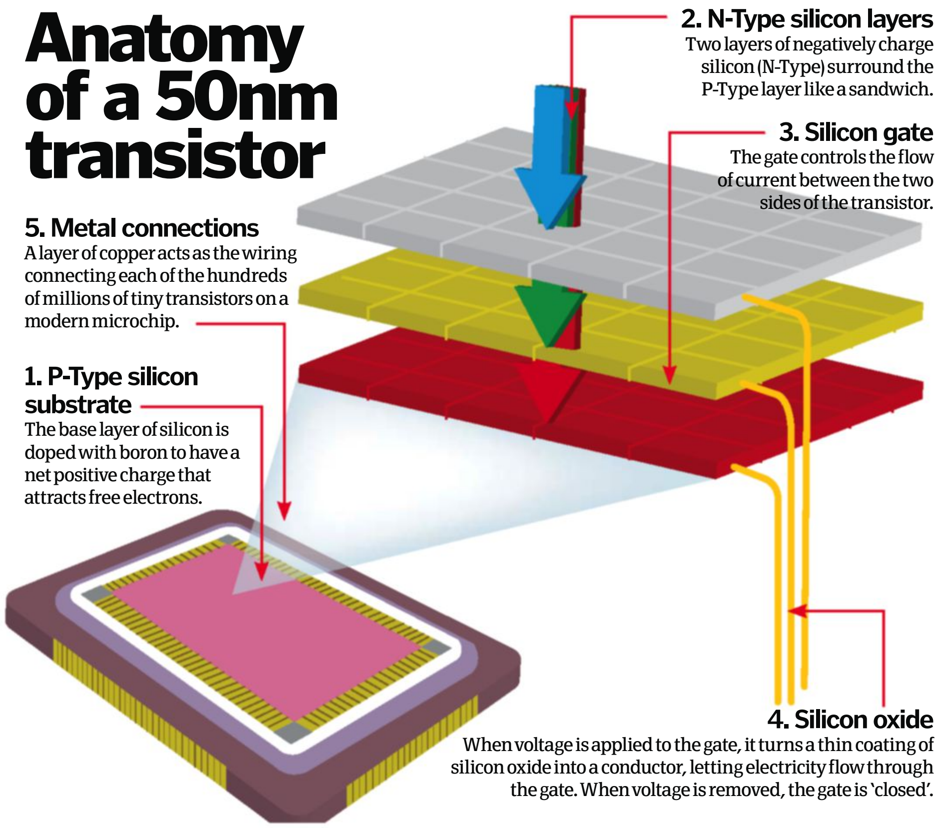
Microchips are manufactured in high-tech clean rooms, or 'fabs', to keep contamination to an absolute minimum

© NASA

Microchip fabrication

Microchips start as highly polished silicon discs, laser-sliced to one millimetre (0.04 inches) thick. The nanoscale components of the chip (transistors, resistors, capacitors, etc) are then built upwards layer by layer. Modern chips have as many as 40 layers. The design for each layer is produced as a mask through which ultraviolet laser light is shone. The pattern is imprinted on a layer of photoresistant material. The pattern is then etched away by chemicals, leaving an intricate design in the silicon layer below. The exposed silicon is then treated with doping agents that give the material its desired electrical properties. Layer upon layer of silicon, insulators and photoresist are added until all of the components are constructed. Then, using the same photolithography technique, layers of metal are cut to leave a pattern of copper wires connecting each tiny component of the integrated circuit.

Anatomy of a 50nm transistor



Head to Head MICROCHIP MILESTONES

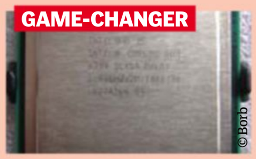
THE FIRST

© Jurii

1. Integrated circuit

In 1958, Jack Kilby dreamed up the idea of constructing all of a circuit's components out of germanium. He won a Nobel Prize in 2000.

GAME-CHANGER

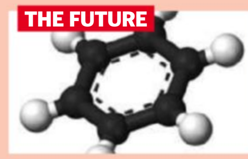


© Borb

2. Intel Core 2 Duo

Intel started selling limited dual-processor chips in 2002, but it was the Core 2 Duo, in 2006, that really revolutionised the industry.

THE FUTURE



3. Molecular transistors

Researchers have turned a single molecule of benzene into a functioning transistor, opening the door for a great leap in computing power.

DID YOU KNOW? Compared to its first microchip released in 1971, Intel's latest chips run 4,000 times faster

Microchips and you

Take a look at just a few of the everyday objects that depend upon microchips

Coffee maker

The microchip inside the Tassimo single-serving coffee maker makes it a 'smart' appliance. The chip reads the barcode on each single-serving disc and calculates the precise amount of water and brewing time to make the perfect cup of coffee, tea or hot chocolate.

© Th145

© Roberts

Digital camera

Prism
A trichoic prism splits incoming light into different wavelengths.

Mixed signals
The signal levels from each of the millions of pixels is reassembled as an image.

Red, green, blue
A 3CCD digital camera has three photo sensors, one for each primary colour.

Pixel power
Each pixel on all three photo sensors uses transistors to convert light into electrical impulses.

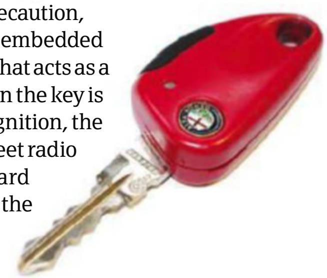
© Nebrot

Clock radio

The transistor radio was the first commercial product in the world that ran by microchip. The millions of transistors on the chip in your clock radio amplify the incoming signal so we can hear the music.

Car keys

As an anti-theft precaution, many car keys are embedded with a microchip that acts as a transponder. When the key is inserted into the ignition, the chip sends a discreet radio signal to a dashboard receiver that gives the green light for the engine to start.

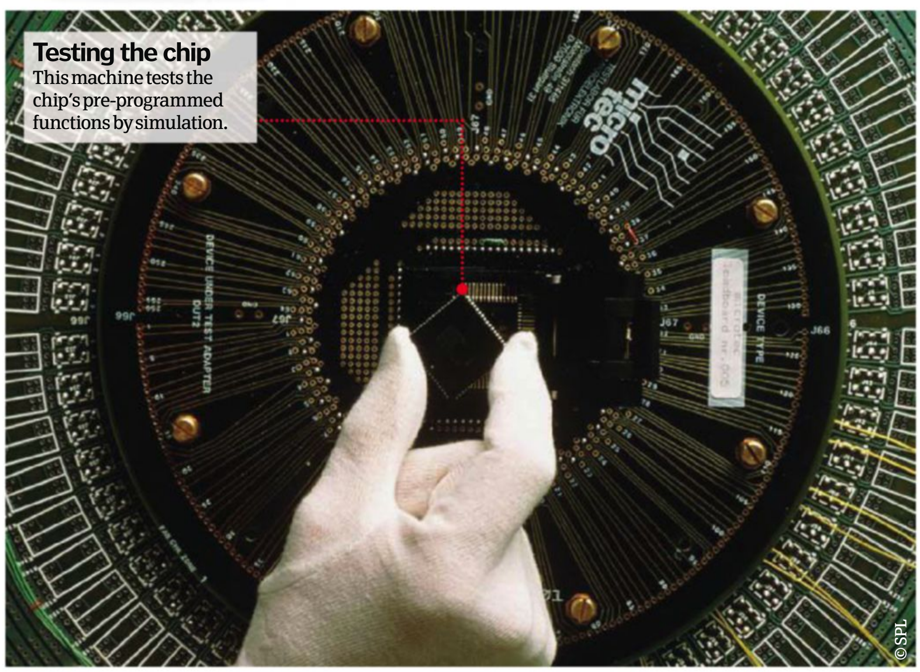


Credit card

The US is following the lead of European banks and ditching the magnetic strip for an embedded smart chip. The chip holds all account information and can only be accessed with the correct four-digit PIN. Credit card fraud in France is down 80 per cent since it was implemented.

A close-up view of a chip-scale atomic clock

© NIST



Testing the chip
This machine tests the chip's pre-programmed functions by simulation.

© SPL

A US Navy engineer in the process of arc welding

What is welding?

The processes and technology of this manufacturing cornerstone explained

Welding is a process in which metals and thermoplastics are joined together to produce an object or structure. These materials are commonly joined by the melting of a filler material, such as steel, at their boundary points, fusing them together. There are three main techniques: gas welding, arc welding and laser welding.

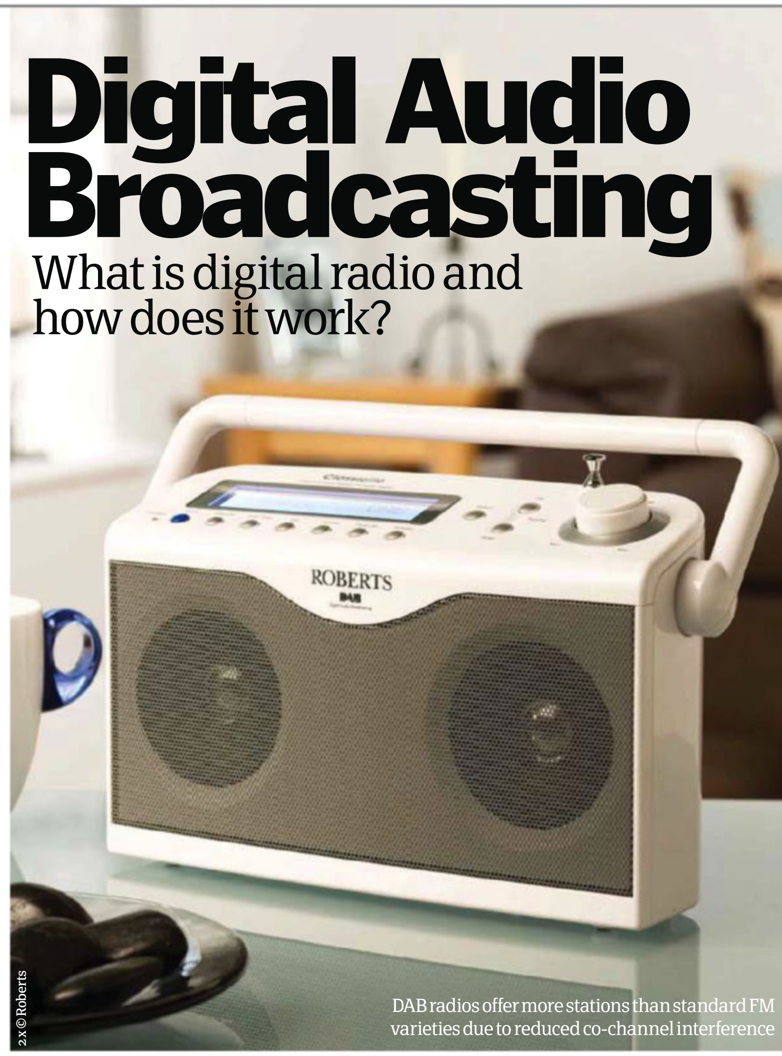
Gas, or oxy-fuel, welding, is the most common type and also the oldest. This process works through the combustion of acetylene in an oxygen stream, with the gas funnelled to a point of focus (ie the welding stick – this can be a handheld or stationary robotic applicator), where it is ignited to produce a high-temperature flame. Gas welding produces a welding flame of 3,100°C (5,612°F) and, as such, is typically used to weld high-alloy steels. However, the flame produced in a gas-based system is typically less concentrated than other methods, leading to greater weld distortion.

Arc welding differs to gas welding significantly. This technique involves melting the work materials through an electrical arc. This is generated by attaching a grounding wire to the welding material and then placing another electrode lead against it, itself attached to an AC/DC power supply. When the electrode lead is drawn away from the materials it generates an electrical arc (an ongoing plasma discharge caused by the electrical breakdown of gas), which through its expelled heat, fuses the materials. Unlike gas welding, arc welding produces a more concentrated weld point.

Finally, laser welding – which is one of the newest forms of welding – uses a high-energy beam to meld materials. As the laser has a high-energy density, this technique can achieve a deep penetration and incredibly focused weld, with little surrounding distortion. Due to this, laser welding is commonly used in large industrial applications, where speed and finesse are of great importance.

Digital Audio Broadcasting

What is digital radio and how does it work?



2 x © Roberts

DAB radios offer more stations than standard FM varieties due to reduced co-channel interference

Digital Audio Broadcasting (DAB) is an increasingly widely adopted format used to transmit audio to radio sets. In contrast to FM radio, which remains the favoured standard worldwide, DAB is transmitted at a far higher frequency range and employs far greater data compression algorithms and audio codecs. This grants the format both major advantages and disadvantages over transmission on standard FM and AM formats.

DAB's key advantage is that through the use of multiplexing – a process of grouping various data streams into one signal – and compression (in the form of specific audio codecs and small bit rates), a large selection of radio channels can be packed into a narrow band of broadcastable frequency. This means that more channels can be broadcast over a smaller area and, crucially, without interference.

This lack of interference is another major benefit of DAB and is achieved through Coded Orthogonal Frequency Division Multiplex (COFDM). This technology splits the DAB signal across multiple frequencies and also across time, meaning that if one part of a station's signal is disturbed by interference (for example, the signal bouncing off buildings) then it can still be recovered by the receiver from another time or place.

Unfortunately, as DAB is still an evolving technology, the major downside with the format is that in some cases the compressed audio stream can result in worse audio fidelity than over standard FM radio. Recently, however, the DAB+ standard was introduced, which utilises a more advanced audio codec (HE-AAC v2) to improve audio quality while keeping the stream bit rate low.

Stencil
1 The first tattoo gun was an evolution of Thomas Alva Edison's Stencil-Pen, which was patented in Newark, USA, in 1876. The pen was originally conceived to replicate images.

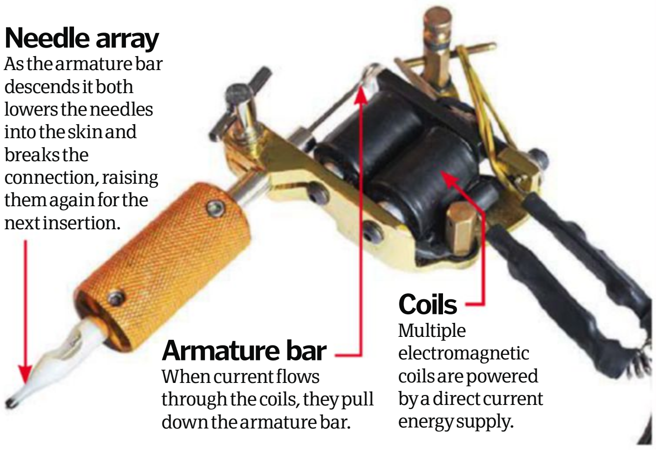
Face
2 Due to rapid improvements in the precision of tattoo guns, a new form of facial tattooing has emerged in the last decade called dermapigmentation, a kind of permanent cosmetics.

Misnomer
3 Interestingly, many professional tattoo artists look down on the term 'tattoo gun'. Most who work in the industry prefer to use the terms 'tattoo machine' or 'tattoo iron'.

Control
4 Modern tattoo guns offer super-refined control over their operation, allowing the artist to select the depth, force and speed of the needles' application to the skin.

London
5 The first proper tattoo gun was patented in London by engineer Samuel O'Reilly in 1891. The first coil-based tattoo gun was also patented in London.

DID YOU KNOW? *The Tugaslugabed alarm clock, circa 1910, awoke sleepers by pulling a loop of string attached to one toe*

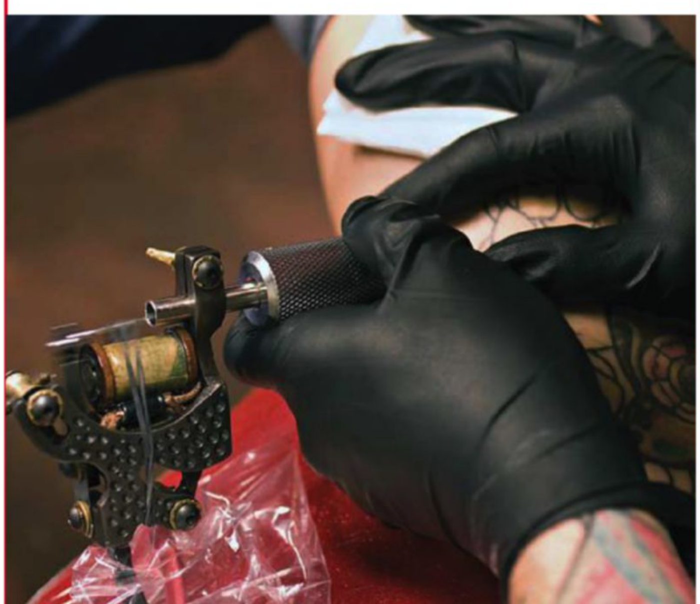


How do tattoo guns work?

The invention designed to transform the skin into a living canvas

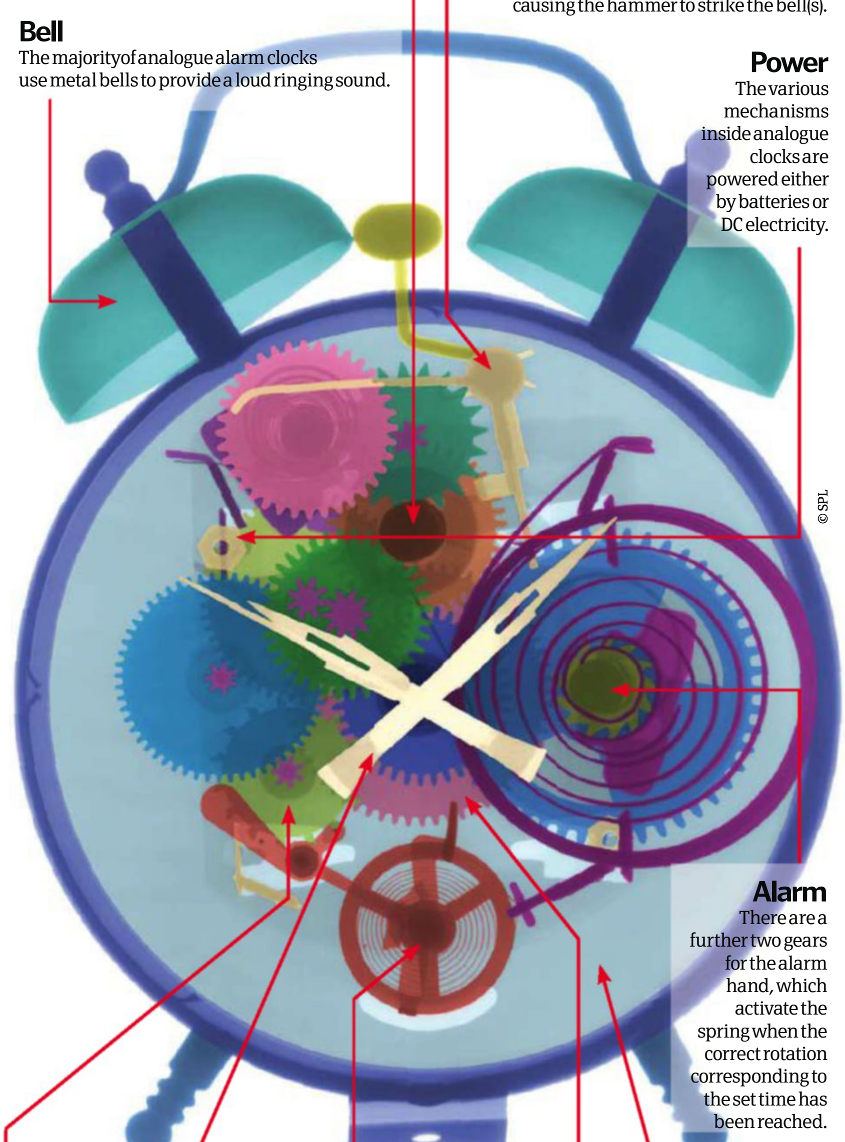
Tattoo guns, also commonly known as tattoo irons or machines, come in a variety of forms. The most common variant, however, is the coil type, which utilises a series of electromagnetic coils to raise and lower needles into the skin to deposit the ink. These devices work by connecting an armature bar via a spring to a base unit, which itself contains between one and three electromagnetic coils. The coils connect to a DC power supply via a sprung U-cable and, when powered, act as an electromagnet, pulling down the armature bar.

Attached to the armature bar is the machine's needle array, and as it descends so too do the needles, piercing the skin and depositing ink just below the surface. At the bottom of the bar's descent its connection with the electromagnet breaks and, as a result, it lifts back to the default position. As such, the needles are constantly drawn up and down at a high speed in a cycle.


An international tattoo convention is held each year in London

Inside an analogue alarm clock

What makes these mechanical time machines tick?

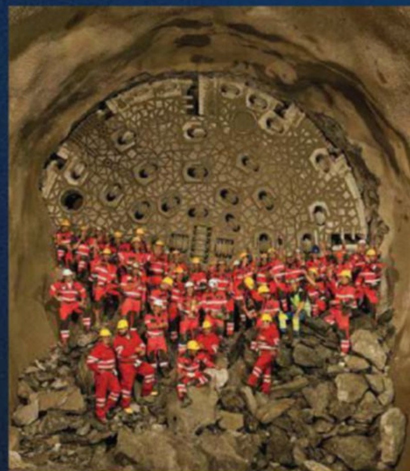


World's largest drill

Our inability to make inroads into some of Earth's most impenetrable terrain was a problem once… then they built tunnel-boring machines!

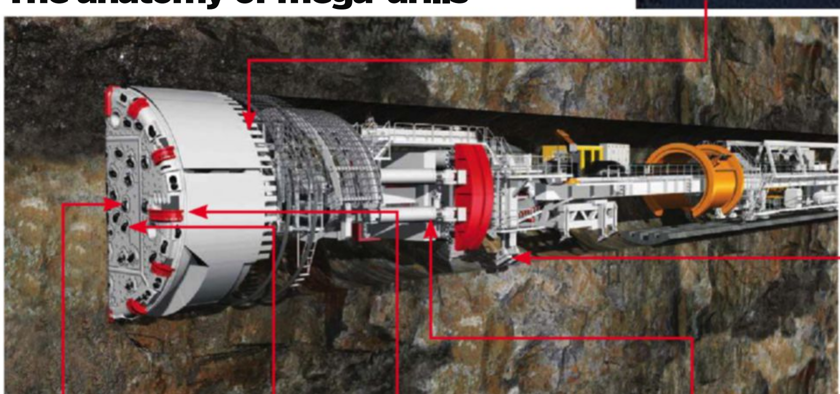
Tunnel-boring machines are designed to drill large-scale excavation holes into terrain that would otherwise be difficult or even impossible to penetrate. They are commonly used in the construction of underground tunnels and bypasses – modern motorway and train tunnels are often built with them – and they are specially designed not just to cut through rock and earth, but crucially to support the tunnel in the process. Additionally, today's most advanced boring machines are engineered to remove debris as it is generated by the drilling process, with rocks and rubble transported to the rear of an assembly on conveyor belts for easy disposal.

Key to any tunnel-boring machine though is its colossal cutterhead, a cylindrical wall of disc cutters and drills that – in partnership with extreme pressure, which is generated by the bore's thrust cylinders – literally crush any material that sits in its path. The largest of these cutterheads currently in operation is a 15.2-metre (49.8-foot)-across Herrenknecht-brand EPB Shield, a record-breaking piece of machinery that was used to carve out chunks of earth in the construction of Madrid's M-30 motorway north tunnel. As you can see on this page, the total assembly is huge and it weighs hundreds of tons.



Engineers, along with a large tunnel-boring machine, celebrate after completing the western tube of the Gotthard Base Tunnel in Amsteg, Switzerland. The tunnel will be a new world record in length once it's completed

The anatomy of mega-drills



Roof bolting unit
This part can rotate around the machine's axis and drills holes into the rock for supporting metal bolts.

Walking device
The rear of the bore and the back-up systems rest on the feet of the walking device. They are lifted as tunnelling progresses and the back-up system follows.

Cutterhead
All the excavation tools are mounted in the cutterhead, which also supports the tunnel face.

Disc cutters
These are mounted in the cutterhead and roll in concentric circles over the tunnel face. The contact pressure crushes the rock.

Buckets
The system's buckets transport the excavated rubble behind the cutterhead onto a conveyor belt system.

Thrust cylinders
These press the rotating cutterhead against the tunnel face.

What is it?

This image shows a record-breaking tunnel-boring machine (15 metres/50 feet across) in the heart of Madrid, Spain. The titanic bore was used in the construction of the city's M-30 motorway north tunnel.

A pump jack in California, USA

© Sanjay Acharya

Pump jacks explained

How do these drilling machines extract oil from deep underground?

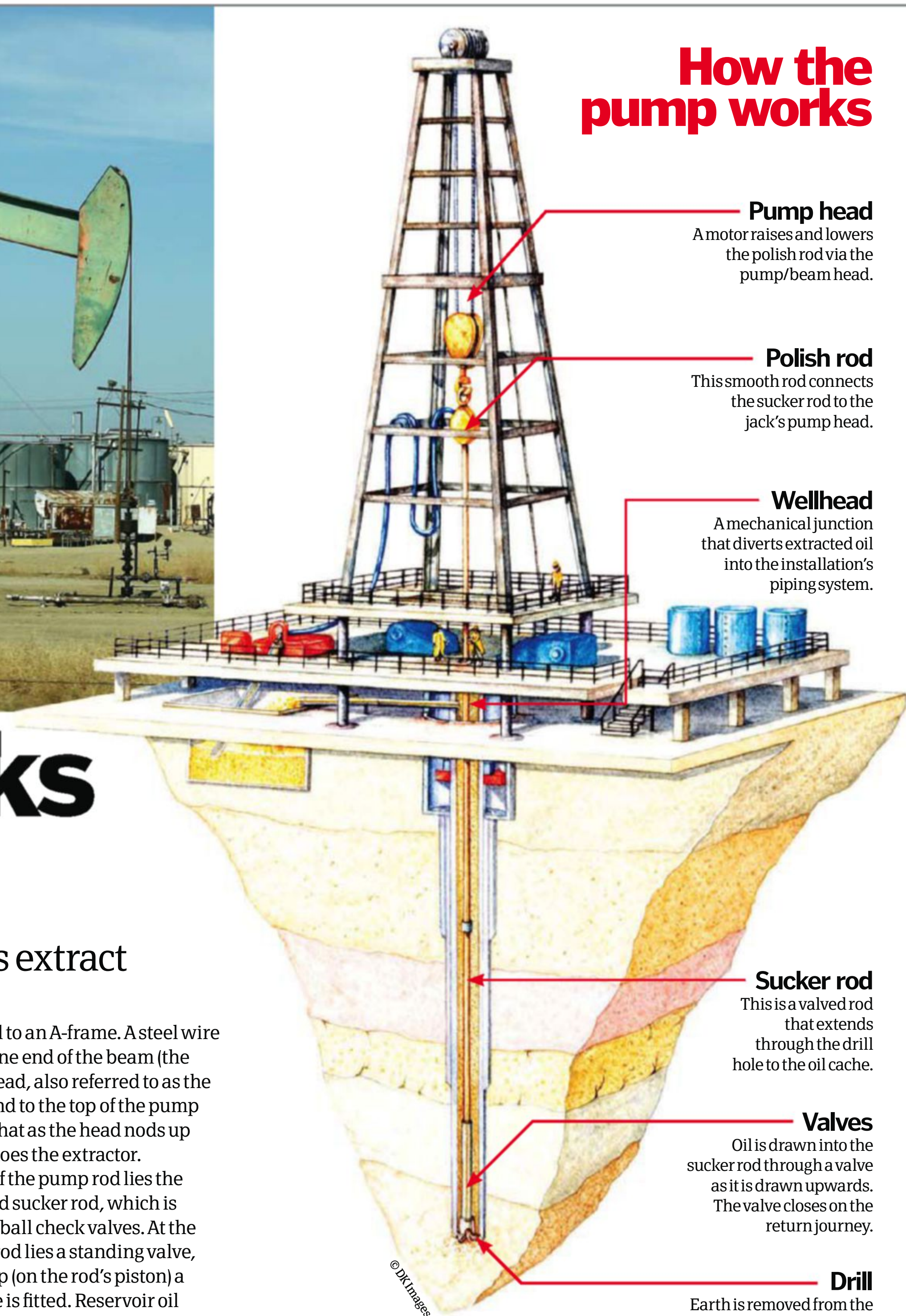
Unlike deep-sea oil caches, oil reserves under solid ground tend to be mixed in with dirt, rocks and a variety of minerals. As such, once drilled, these oil reserves do not freely ascend to the surface for collection and processing, as the bottom hole pressure is inadequate. Consequently, large extraction machines referred to as pump jacks are needed to lift the natural resource to the surface.

Pump jacks work by drawing oil into a valved sucker rod, which is extended down a drill hole by a mechanised lifting engine. The engine itself converts the rotary movement produced by an electric/diesel motor into a vertical reciprocating motion that drops and lifts a pump rod down the drill shaft. A common design for these lifting engines is the walking beam type, commonly nicknamed a 'nodding donkey' due to their physical resemblance to the creature. Here, a motor drives a pair of counterweighted cranks that, in turn, raise and lower one end of a horizontal beam mounted to an A-frame. A steel wire is attached to one end of the beam (the pump/beam head, also referred to as the 'horse head') and to the top of the pump rod, meaning that as the head nods up and down, so does the extractor.

At the base of the pump rod lies the aforementioned sucker rod, which is fitted with two ball check valves. At the bottom of this rod lies a standing valve, while on the top (on the rod's piston) a travelling valve is fitted. Reservoir oil enters the pump through perforations in the drill hole's casing and enters the standing valve. Then, when the sucker rod descends, the travelling valve is opened and oil is transferred. After transference has taken place, the standing valve is opened again to receive more oil, while the travelling valve closes for the oil's ascent to the surface.

Finally, oil is passed from the sucker rod into the pump jack's wellhead, which reroutes it into oil pipelines. The pipelines then carry the crude oil to a processing facility for refinement.

How the pump works



© DK Images

It's easy to see how these pump jacks acquired the name nodding donkeys

© Techcollector

5 TOP FACTS TORPEDO TRIVIA

Variety
1 Modern torpedoes are divided into a wide variety of classes and types. These include lightweight, heavyweight, straight-running, autonomous homing and wire-guided.

Nautilus
2 The first recorded use of a torpedo is 1800, when American inventor Robert Fulton launched a primitive, floating explosive charge from his Nautilus submarine.

Tesla
3 While unconfirmed, it's reported that Nikola Tesla invented a remote-controlled, radio-guided torpedo in 1897. He patented the technology and showed it to the US military.

Launchers
4 Torpedoes are commonly launched by submarines, however they are also carried by attack helicopters and jets, as well as fired from warships via specialised launch tubes.

Warhead
5 Modern torpedo warheads are typically filled with polymer-bonded explosives (PBX). These are used as the explosive pulse they produce is particularly intense and destructive.

DID YOU KNOW? The Sting Ray, one of the two torpedoes now used by the British Royal Navy, entered service in 1983

How torpedoes work

What enables these marine missiles to pack such an explosive punch?


This US Navy torpedo launcher is being tested during training exercises

A torpedo is a self-propelled missile used to engage targets underwater, exploding upon contact with a vessel's hull.

Torpedoes are classified depending on their launch mechanism, warhead composition and manner of propulsion. Launch platforms can include: submarine missile tubes – where the torpedo is directly fired from a torpedo bay underwater; ship-mounted, gas-powered cannon arrays; and via trajectory-planned freefall from helicopter gunships.

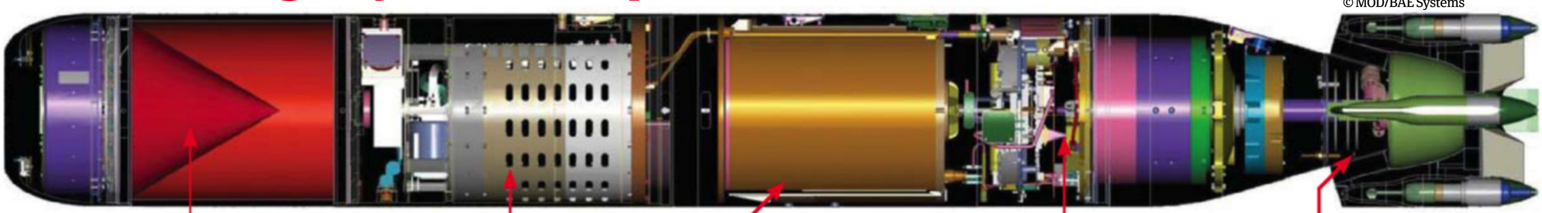
Torpedo warheads are commonly constructed from an aluminised explosive, such as Torpex or PBX. The aluminium centre is used as it helps generate a sustained explosive pulse, which is particularly destructive against armoured, underwater targets. Further, the actual warhead is usually shaped (normally conically) in order to maximise hull penetration. This leads to far greater internal damage to the unfortunate target, potentially critically breaching and flooding the vessel.

Propulsion and guidance are handled by systems within the actual torpedo. Propulsion is usually delivered by an electric battery stack in partnership with a hydraulic/mechanical actuation system. This modern tech enables torpedoes to be stored for lengthy periods of time without losing power efficiency and drive speed. Guidance is handled by an array of gyroscopic sensors along with a central navigation data system. This is fed information by both the launcher and also via active or passive acoustics – the former working by the torpedo generating sound signals which echo off their target like sonar, and the latter working by directly homing in on the target's noise profile.

Currently, the Royal Navy uses two main torpedoes, the Spearfish and Sting Ray, while the US Navy fields five of varying types and weights.

Inside a Sting Ray Mod 1 torpedo

© MOD/BAE Systems



Warhead
A new insensitive munition-shaped charge warhead ensures a large isotropic blast resulting in great damage to the target.

Navigation
A solid-state inertial measurement unit is used to support complex tactical software modes to evade modern countermeasures.

Power
A magnesium/silver chloride battery stack provides power for on-board electronic systems, as well as delivering a longer range and greater reliability.

Electronics
A digital signal processor enables improved target classification and a next-generation autopilot allows execution of complex tactical software routines.

Propulsion
An electro-mechanical actuation system generates forward momentum. The absence of pumps and fluids reduces maintenance requirements.

Camera autofocus

© Samsung

Autofocus is an important component in photography so let's take a closer look at how it really works

Autofocus (or AF) is one of the key elements in a camera and can determine how successful your final photographs are. Many rely solely on the camera's autofocus setting when shooting as it can be a guaranteed way to ensure your shots are sharp.

There are two types of autofocus: active, which is commonly used in point-and-shoot compacts, and passive, which features more in high-end camera models. Arguably passive is the quickest and more reliable of the two and has two specific focus systems: phase detection and contrast detection.

Phase detection is the most common due to its speed and focus accuracy. Once you have composed your image in-camera you will need to depress the shutter button halfway so the camera can find a focal area to lock on to. While this is happening, the image you intend to shoot will enter the lens and get split into two. Depending on the distance between your subject and camera lens these images should run evenly alongside each other before being separated through two microlenses and then projected individually onto two small AF sensors. The images should each meet the AF sensors directly for the image to be in focus and should not overlap or be too far from each other – in other words, out of phase. By comparing the projected images on the two sensors, the camera's built-in AF unit will then ascertain whether the shot is front focused, back focused or fine as it is.

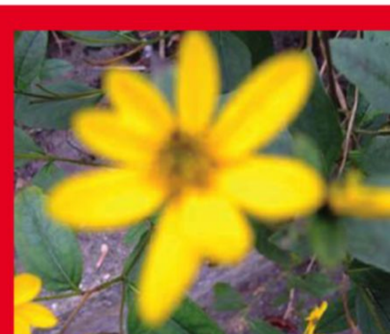
Depending on the results, the AF unit can determine how far and in what direction the lens needs to be moved in order to phase and accurately focus the photograph. Directing a small motor that is powered by the camera's battery, the lens will then be repositioned at the right distance from your subject to ensure you get the optimum blur-free results.

It may seem like a long process but all this in fact takes only a fraction of a second and is one of the most sure-fire ways to get great snaps.

Focus locking

The majority of cameras – particularly compacts – have only one central focus area; this means your final image's focus area will fall within the centre of the frame and often in the background of a large scene. If, however, you want to focus on a subject in the foreground, which may be slightly off-centre, you will need to override the camera's automatic instincts.

Begin by repositioning your camera so the foreground subject is in the centre of the frame. You can now focus the camera by pressing the shutter-release button down halfway. Holding your finger in place will lock the camera's focus, allowing you to position the camera back to the original composition ready to shoot.



Autofocus settings
1 Most cameras offer both single AF and continuous AF shooting modes. Use continuous AF when you're photographing fast-moving subjects as it helps to keep action shots sharp.

Eyes on the prize
2 When shooting portraiture or even wildlife, it's a good idea to focus the camera on your subject's eyes as this is where the viewer will naturally be drawn to.

Rule of thirds
3 When shooting a landscape always try to focus the camera one-third of the way into the frame; this will help to ensure that as much of the image is in focus as possible.

Macro mode
4 Don't forget to use your Macro mode when capturing closeups. This will enable you to shoot at a closer distance to your subject, filling the frame with much more detail.

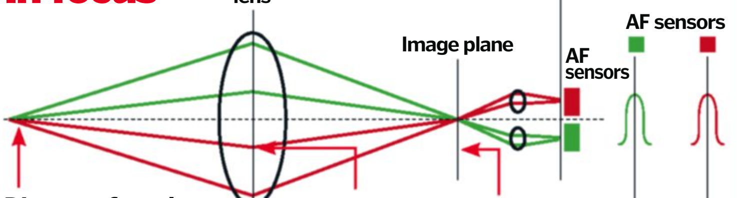
Set a focus point
5 Most cameras offer focus point settings that enable you to adjust where in the image the camera should home in on. Explore your camera's menu settings to find out what options are available.

DID YOU KNOW? *Polaroid cameras first used SONAR technology to determine the correct AF distance required*

Phase-detection autofocus in action

Take a closer look at the main principles of phase detection

In focus

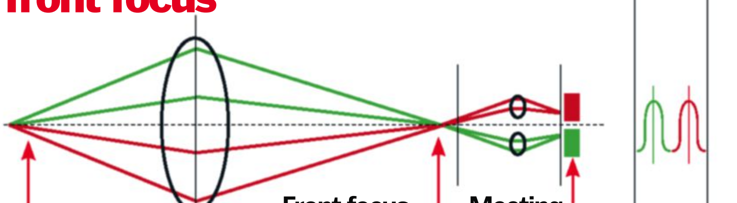


Distance from lens
The furthest point represents how far the subject is from the camera lens.

Split of light
The prospective image will be split in two when it enters the camera lens to determine the focus accuracy.

Image plane
The two images should converge evenly at the image plane before projecting onto the AF sensors.

Inaccurate front focus

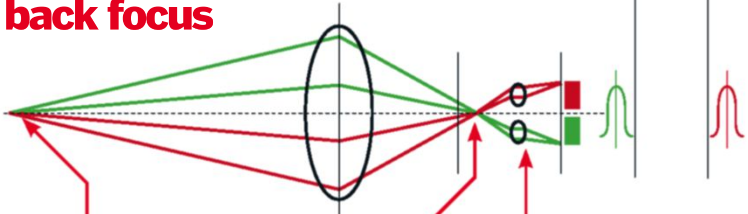


Distance from lens
The subject is closer to the lens so is more likely to be out of focus due to the short distance.

Front focus
An example of front focus as the two images have converged too soon so they overlap before reaching the image plane.

Meeting the sensors
The split images are too close together to meet the AF sensors accurately.

Inaccurate back focus



Distance from lens
The subject is at a notably further distance from the camera lens here.

Back focus
Due to the distance between the subject and lens the images converge too late to pass through the microlenses accurately enough.

Microlenses
Once the split images meet at the right point, they should pass through the microlenses to be directed onto the AF sensors, but the images are not aligned here resulting in blurriness.

Active versus passive

There are two different types of autofocus: active and passive. Most point-and-shoot compacts use an active system whereas pro DSLR cameras rely on faster and more accurate passive AF. What really sets them apart is how they measure the distance between the subject and camera in order to set the correct focus.

Active AF systems determine distance using infrared light that reflects off the subject back into the lens. The camera's AF system will then work out how long in time it takes to receive the bounced light back before calculating where the lens needs to move to focus the frame. This is rarely instant and you are limited to shooting at shorter distances.

Passive autofocus systems, on the other hand, determine distance by analysing the proposed image first without using infrared rays. Using either phase-detection or contrast-detection techniques, the camera relies on small AF sensors to establish where the lens needs to be placed in order to focus your shot.

Where the phase-detection system sits inside the camera

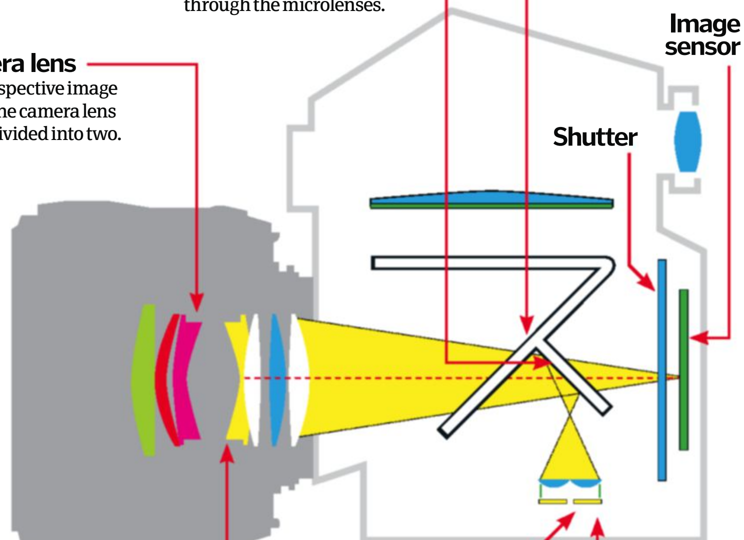
Sub-mirror
This smaller mirror reflects the two split images down through the microlenses.

Main mirror
This mirror flips up when the shutter is pressed.

Image sensor

Camera lens
The prospective image enters the camera lens and is divided into two.

Shutter



Lens-driving controller
Receiving the information from the AF unit, the lens-driving controller will then instruct a motor to reposition the camera lens as required.

Small AF sensors
The two AF sensors receive the split images individually and determine how in focus the final image will be based on their alignment.

AF unit
The camera's autofocus unit then calculates how far the lens will need to be adjusted in order to correct an out-of-focus photo.

Step 1
The camera will automatically focus in on the centre of the frame and usually on the largest area, which in this image is the background.

Step 2
To bring the flower into focus the shot is re-composed, placing the bloom in the centre. The shutter is pressed halfway to focus on the flower and held.

Step 3
Still holding down the focus, the camera is moved back into its original position and the shot is taken. The flower is now perfectly in focus.

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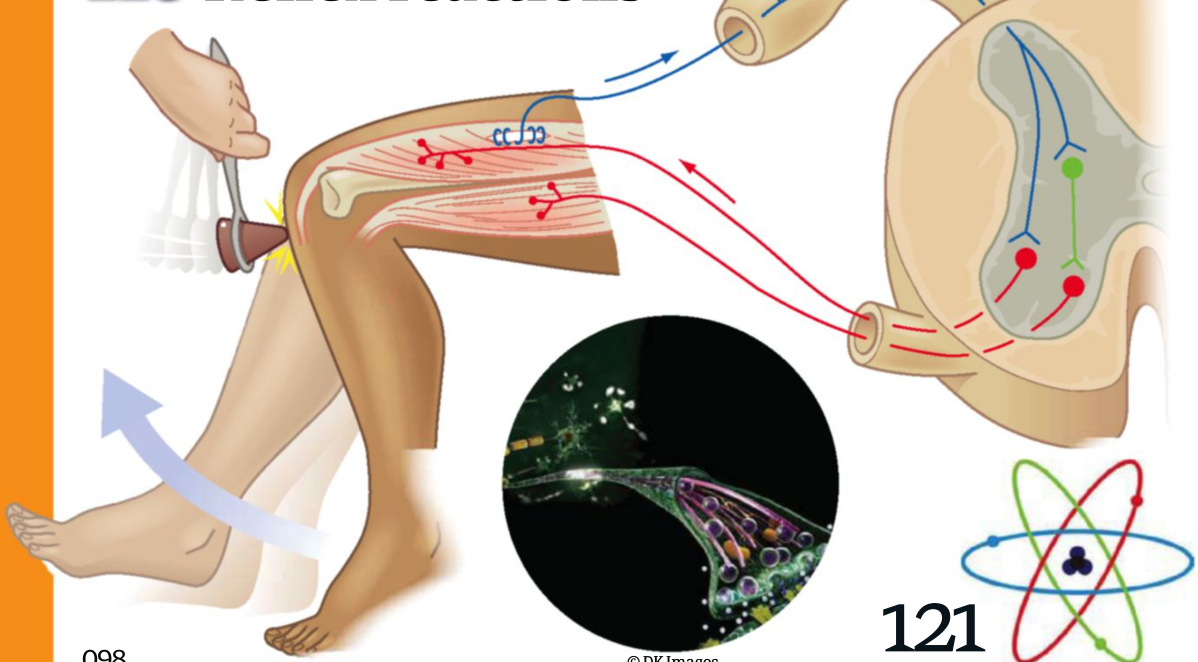
SCIENCE

110 Reflex reactions



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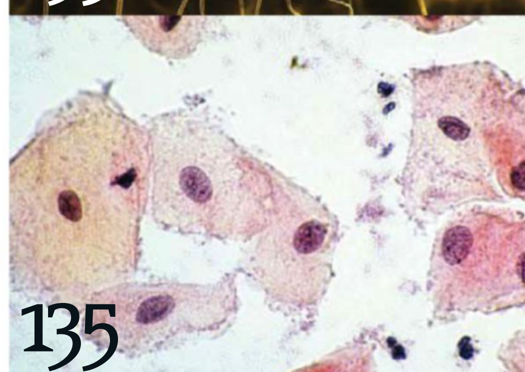

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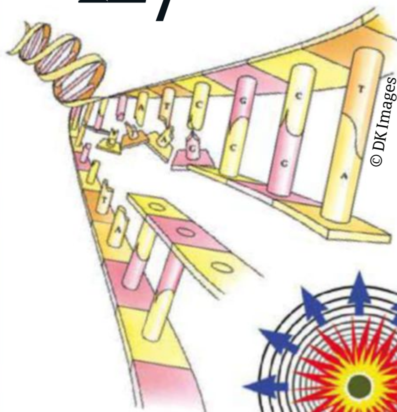

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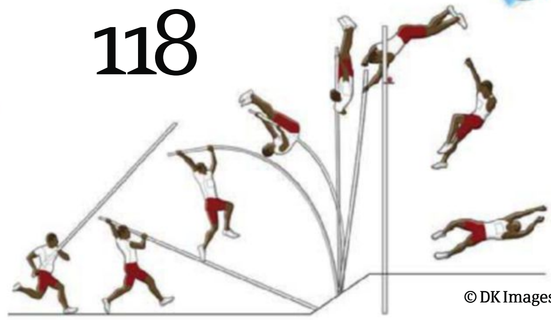

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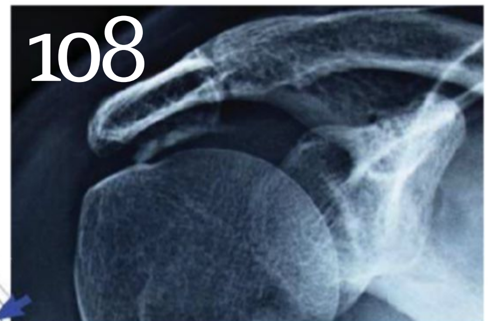

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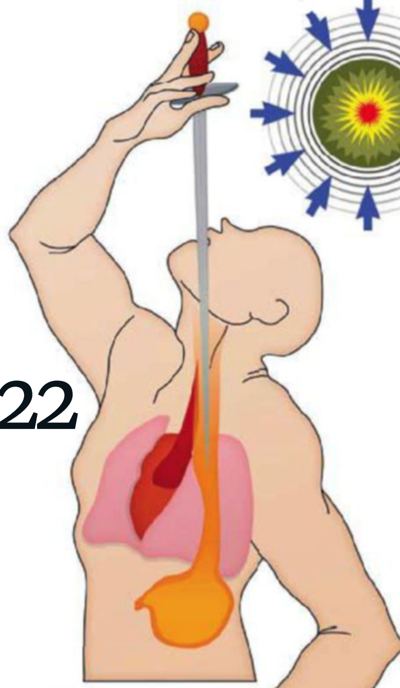

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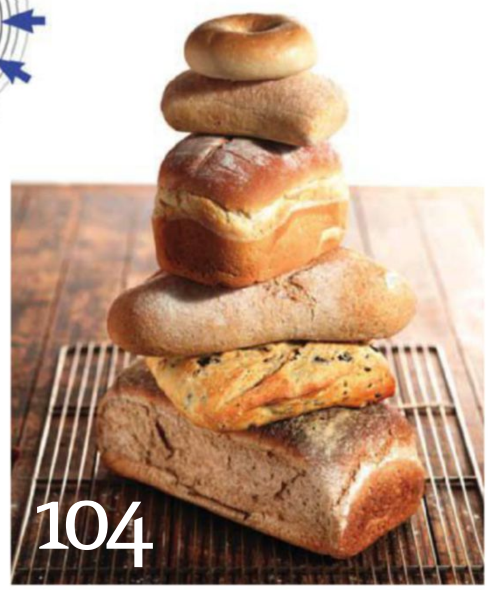

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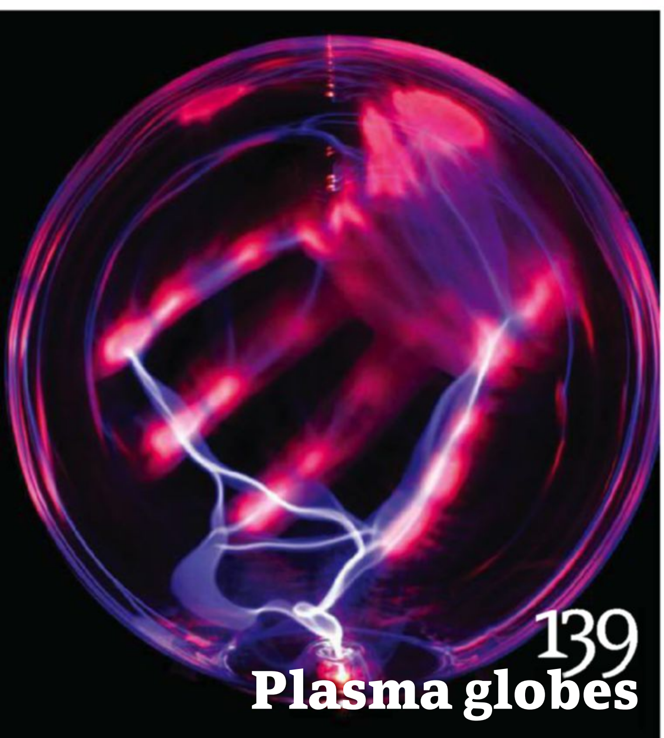
The ageing process



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Plasma globes

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Laser fusion power

THE RISE OF SUPER BUGS

How the widespread overuse of antibiotics is proving that too much of a good thing can be catastrophic

Antibiotics are, without question, the miracle drugs of the 20th Century. Penicillin, the first widely produced antibiotic, saved more soldiers' lives during the Second World War than the Sherman tank. Since the Forties, researchers have discovered newer, more powerful strains of antibiotics to treat everything from the common ear infection to the most exotic tropical disease. When a young mother takes her sick child to the doctor, complaining of high fevers, green mucus and listlessness, she doesn't want to hear the speech about drinking lots of liquids and getting plenty of rest – she wants something that will alleviate the symptoms almost instantly. She wants antibiotics. And sadly, many doctors are more than happy to prescribe them, whether patients need them or not.

According to the United States Center for Disease Control, antibiotics are wrongfully administered in almost 50 per cent of cases. On an individual level, there's no real harm in unnecessarily taking an antibiotic, but widespread abuse of antibiotics has a potentially catastrophic effect on society as a whole. The more antibiotics that humans (and the animals we eat) take, the quicker bacteria evolve and the stronger they become. And what happens when bacteria evolve so significantly that our beloved antibiotics no longer have any effect on them? We're about to find out.

Antibiotic resistance is one of the world's most serious health threats. We are already witnessing the rise of so-called 'superbugs', pathogenic bacteria that are immune to traditional antibiotic treatment. The best-known superbug is MRSA, short for methicillin-resistant Staphylococcus aureus. Like several

> "The more antibiotics we take, the quicker bacteria evolve and stronger they become"

5 TOP FACTS SUPERBUGS

Prescription for chaos
1 According to the US Center for Disease Control, half of all antibiotics are inappropriately or unnecessarily prescribed, reducing the effectiveness of life-saving drugs.

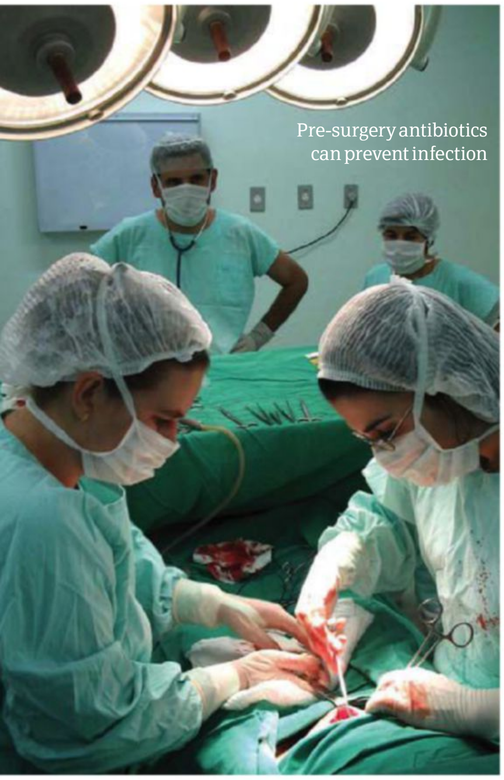
The HIV connection
2 Results have shown that HIV-positive individuals are somewhere in the region of 20 per cent more likely to transmit and carry drug-resistant bacterial infections.

'Extreme' TB
3 More than 2 billion people are infected with TB. There's also a rise in Extreme Drug Resistant (XDR) TB, which doesn't respond to first-line or second-line antibiotics.

An emerging superbug
4 Drug-resistant strains of gonorrhea are cropping up around the world. Nearly 25 per cent of new infections in 2009 showed resistance to widely prescribed antibiotics.

You want me to do what?
5 As disgusting as it sounds, one of the most effective ways to cure a C difficile infection is to implant healthy faecal matter from a close relative via an enema.

DID YOU KNOW? A 2009 study in Turkey found MRSA bacterial colonies on one out of eight doctor cell phones



Pre-surgery antibiotics can prevent infection

other drug-resistant bugs, MRSA spreads quickly through hospitals on the unwashed hands of health workers and patients. Staph infections are nasty enough. If allowed to enter the body, they can target the lungs (pneumonia), the heart (endocarditis) and even the bloodstream (bacteraemia). MRSA is staph on steroids, because it has evolved to be resistant to the most effective antibiotics for curing the infection. Imagine going into the hospital with a sprained ankle and leaving with a drug-resistant case of pneumonia.

So how do common bacteria like S aureas and E coli evolve so quickly from a curable annoyance to a potential pandemic? Let's start by dusting off our Darwin. Evolution by natural selection requires three things: reproduction, variety and selective pressure. Bacteria are masters of reproduction. Under the right conditions, a bacterial colony will double in size every ten minutes. They do this through binary fission. Essentially, the bacterium makes a copy of its own DNA, then splits in two. With so much copying and splitting, some mistakes (mutations) are going to be made. These genetic mutations increase the variety of traits that the bacteria can express. Variety is not only the spice of life, but also the engine of evolution.

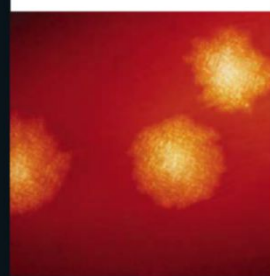
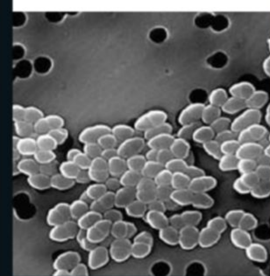
When a doctor administers an antibiotic to kill off an infection of S aureas, this applies a selective pressure to the bacterial colony. Bacteria that express beneficial

TYPES OF SUPERBUG

Superbugs come in several flavours, all mutant variations of relatively common and even harmless bacteria that normally live in or on the human body. Fuelled by the overuse of antibiotics, these novel strains now have deadly potential

	Methicillin-resistant Staphylococcus aureus (MRSA)	Shiga Toxin-producing Escherichia coli 0104:H4	Drug-resistant Clostridium difficile NAP1 (C diff)	Vancomycin-resistant Enterococci (VRE)
YEAR DISCOVERED	1961	EARLY-NINETIES	EARLY-NOUGHTIES	1986
INFORMATION	While staph infections are common and usually curable with standard antibiotics, MRSA is stubbornly resistant to a family of antibiotics called beta-lactams. Most MRSA cases start as skin infections around wound sites, often exhibiting pus-filled boils. Life-threatening cases can involve blood infections, surgical site infections and pneumonia.	E coli is transmitted to humans through food or water contaminated with animal faeces. Most cases can be treated with antibiotics, but the deadly strain 0104:H4 is resistant to most major classes. In fact, antibiotic treatment triggers the release of toxins that make the symptoms – violent diarrhoea, kidney damage and blood clots – far worse.	Like MRSA, C diff thrives in hospital settings and is resistant to many treatments. A C diff infection is most often caused by prolonged antibiotic treatment. While antibiotics kill off unrelated infections, C diff remains unharmed, colonising the gut and releasing a powerful toxin that causes colitis, severe diarrhoea and even perforation of the colon.	Enterococci bacteria live in the healthy human gut and female genital tract. But certain conditions can cause them to grow out of control, leading to urinary tract and even blood infections. The most powerful trigger is treatment with the antibiotic vancomyacin. While this kills off harmful and healthy microbes, the enterococci stay behind and thrive.
RESISTANT TO	Methacillin, oxacillin, penicillin, amoxicillin.	Eight classes of antibiotics including beta-lactams (penicillins), tetracycline and cephalosporins.	C diff infections emerge after treatments with penicillins, clindamycin, cephalosporins and fluoroquinolones.	Vancomyacin.
RISK ENVIRONMENTS	Hospitals, locker rooms, day care centres, university dorms, barracks, prisons.	Unwashed fresh fruits and vegetables pose the greatest risk of carrying the disease.	Hospitals. C diff spores can live on contaminated surfaces for months.	Long-term hospital stays, especially with use of urinary catheters.
NUMBER OF DEATHS	18,650 deaths in the US in 2005; 148 deaths in the UK in 2009.	44 deaths in the 2011 European outbreak.	Deaths are still rare (2% mortality rate), but that's a 35% increase since 2005 .	Rare from VRE, but patients with serious illnesses have a 38% mortality rate.
TREATMENT	Cleaning, incision and drainage of the infected wound. Testing to determine exact bacteria type and use of a targeted antibiotic.	Hydration, pain relief and close monitoring for severe symptoms like kidney failure or blood clots.	It can resolve itself a few days after antibiotic treatment ends. Others will need a stronger course of antibiotics like metronidazole.	Lab tests will indicate which antibiotics other than vancomyacin can be used to treat the infection.
PREVENTION	Avoid skin-to-skin contact with hospital patients or others with open wounds. Wash hands thoroughly after hospital visits, trips to the gym, and so on.	Thoroughly wash fruits and vegetables and fully cook all meat and poultry products before eating.	Ensure hospital staff wash hands before touching you or your food. Transmission by health-care workers is the number-one transmission method for C diff.	Better hospital sanitation, limited use of antibiotics and frequent changing of catheters.



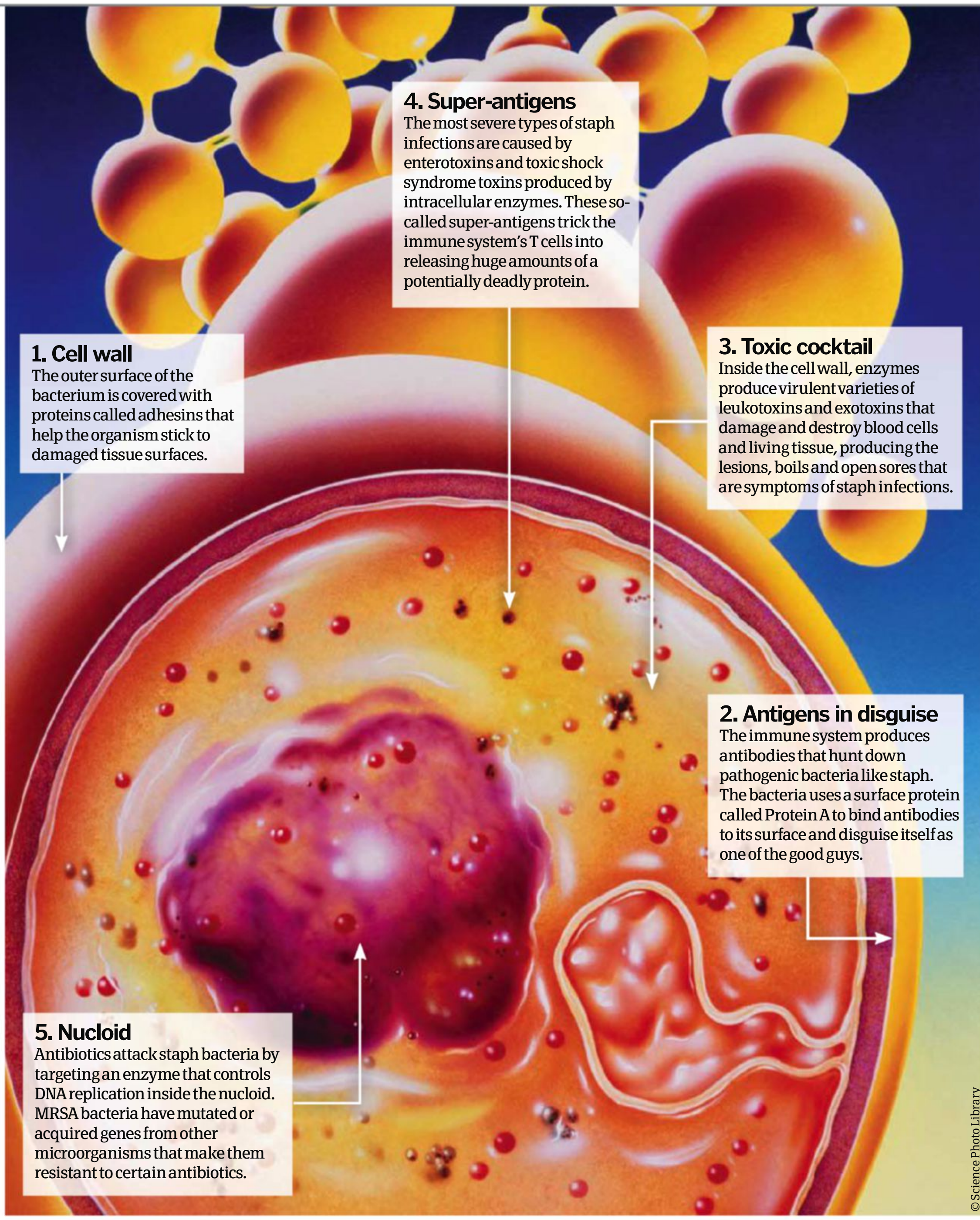
traits – such as the ability to pump antibiotics out of their system – will survive, while the others will be wiped out. The surviving bacteria will then repopulate the colony, and the next time the antibiotic is applied, it will be completely useless.

Bacteria are not only evolutionarily efficient, but they are also cheaters. Through a process called conjugation, two bacteria can share slices of genetic material that carry beneficial traits, skipping the randomness of natural selection altogether. By this method, some bacteria have developed techniques for disguising themselves to antibiotics, blocking the entrance to the cell wall, and even tricking the body's own immune system to release toxic levels of proteins.

The best weapon against the spread of superbugs is to reduce our overall consumption of antibiotics – including the beef, pork and dairy industries, which are responsible for administering 70 per cent of the antibiotics in America – and to improve hygiene and sanitation at hospitals, where these infections thrive and spread.

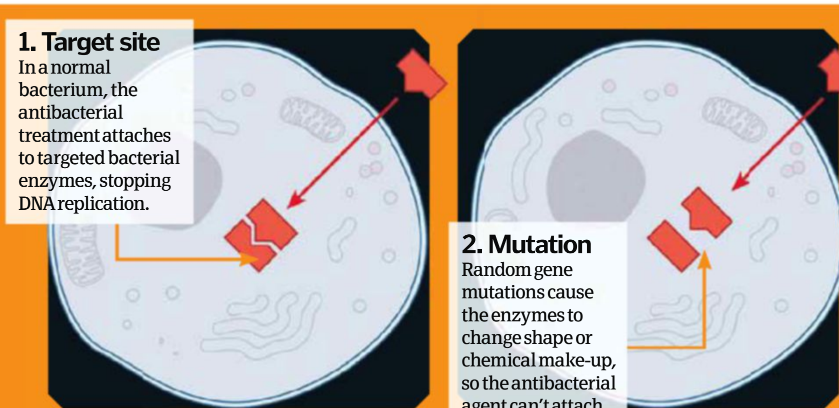
Inside an MRSA bacterium

MRSA is a drug-resistant strain of Staphylococcus aureus, one of the most virulent and violent bacteria we know. Staph infections come in all flavours, from diarrhoea-inducing food poisoning, to skin lesions, to potentially fatal cases of toxic shock syndrome. MRSA is a staph bacterium that has mutated or otherwise acquired genetic traits that defend it against attacks from antibiotics.

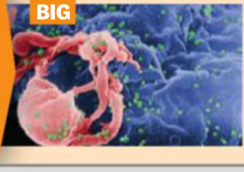


Why antibiotics don't work

Bacteria exist in our bodies by the billions. Up to 1,000 different species live in the human gut alone. With such a large and thriving population, it's easy to understand how a few bacteria might randomly acquire traits that make them more resistant to 'killer' drugs like antibiotics. Through Darwinian evolution, the strongest, most resistant bacteria survive. Bacteria acquire these resistant traits through two mechanisms: genetic mutations or by genetic transfer from other organisms. These new traits effectively block antibiotic particles from reaching their target enzymes inside the bacterial cell wall.



BIG



1. HIV/AIDS
There are 33 million people worldwide living with HIV, the vast majority in sub-Saharan Africa. Around 2 million people die of AIDS every year.

BIGGER

2. Spanish Flu
In 1918, a global flu pandemic claimed the lived of an estimated 40 million people, sometimes within hours of exhibiting the first symptoms of the virus.

BIGGEST

3. Black Death
The superbug to end all superbugs, the bubonic plague bacteria wiped out half of Europe's population during the 14th Century and around 200 million people worldwide.

DID YOU KNOW? *While surgical masks block bacterial infections, virus particles are tiny enough to pass through*

Superbugs and hospitals

For bacteria, a hospital is like an evolutionary experiment gone mad. Think about how many antibiotics are prescribed in a hospital. And think about the broad range of pathogenic bacteria that walk through the door on the skin and in the mouths, noses, ears and open wounds of patients. Even after we bomb these bacteria with drugs, a few hardy mutants will survive. These germs pass easily from patient to patient on unwashed hands and contaminated surfaces. A healthy patient might come in for a couple of stitches and leave with a raging, drug-resistant infection.

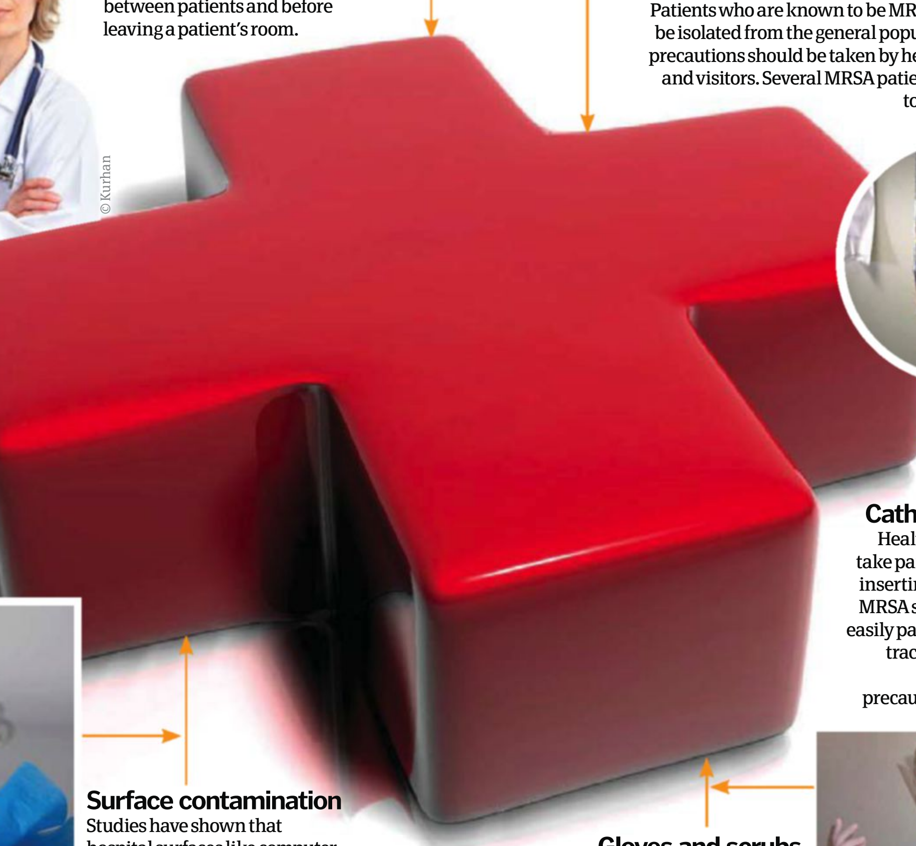
© Kurhan

Health-care workers

Skin-to-skin contact is the most effective way to spread a superbug. Health workers must wash hands between patients and before leaving a patient's room.

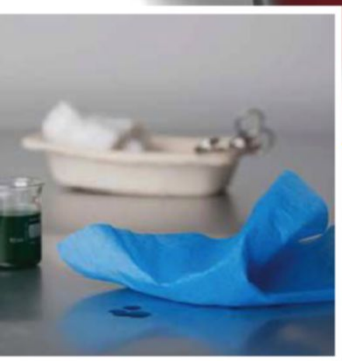
Isolation and cohorts

Patients who are known to be MRSA positive should be isolated from the general population and special precautions should be taken by health-care workers and visitors. Several MRSA patients can be bedded together as a cohort.



Catheters and IVs

Health workers need to take particular care when inserting catheters or IVs. MRSA skin infections can easily pass into the urinary tract or bloodstream if proper hygienic precautions aren't taken.

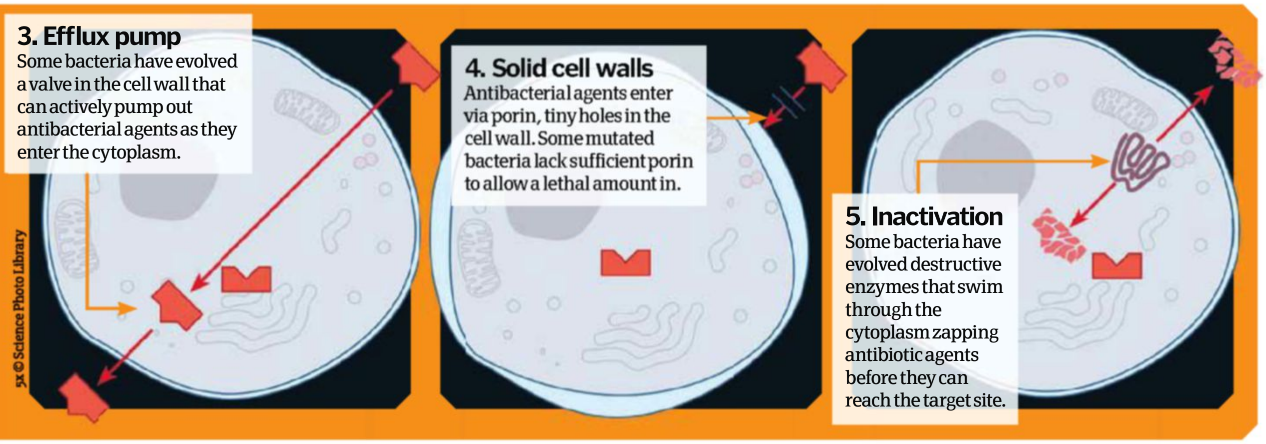


Surface contamination

Studies have shown that hospital surfaces like computer keyboards, tap handles, pens and doctors' scopes contain surprisingly high levels of pathogenic bacteria.

Gloves and scrubs

To further reduce the transmission of superbugs on skin and clothing, some hospitals are requiring the use of disposable gloves and temporary clothing like scrubs in high-risk areas.



3. Efflux pump

Some bacteria have evolved a valve in the cell wall that can actively pump out antibacterial agents as they enter the cytoplasm.

4. Solid cell walls

Antibacterial agents enter via porin, tiny holes in the cell wall. Some mutated bacteria lack sufficient porin to allow a lethal amount in.

5. Inactivation

Some bacteria have evolved destructive enzymes that swim through the cytoplasm zapping antibiotic agents before they can reach the target site.

5x © Science Photo Library

10 TIPS TO PREVENT THE SPREAD OF SUPERBUGS

1 Recognise that the overuse or misuse of antibiotics is a major cause of increasing antibiotic resistance, and be conscious of this.

2 Understand that antibiotics can only cure bacterial infections, and not viral infections such as common colds or the flu.

3 Never take leftover antibiotics that you find in your house.

4 When prescribed antibiotics, follow your doctor's instructions and take the full course, which is usually the entire bottle.

5 Never take antibiotics prescribed to a friend just because you have the same symptoms as them.

6 Unless your symptoms are extremely severe, make sure that you take the time out to have tests taken in order to determine the exact bacterial pathogen that is affecting you. This will consequently allow your doctor to prescribe a targeted antibiotic rather than a wider spectrum treatment that is unlikely to be as effective.

7 Even if you and your doctor feel that you probably have an infection, ask about alternative treatments and remedies that might resolve the infection before resorting to the use of antibiotics.

8 Try to support farms and dairies that do not use prophylactic antibiotic treatments in order to stave off infections among their animals. Overuse of agricultural antibiotics is, in fact, one of the greatest causes of antibiotic resistance.

9 Don't use low-level antibiotics to resolve chronic acne. Try other methods instead.

10 Health-care professionals and hospital visitors must be vigilant about hand washing and overall sanitation, particularly when around patients who are immuno-compromised.

Hair loss

How do hair regrowth products work?

Male and female pattern baldness is caused by hair follicles reacting to the testosterone hormone. Alopecia areata damages hair follicles due to imbalances in the immune system caused by stress, disease, infection, chemotherapy or genetic predisposition.

For male pattern baldness, finasteride can be used to block the impact of testosterone on hair follicles and can restore some of the hair lost. Minoxidil lotion can be used for male and female pattern baldness and can reduce or stop hair loss in the long term.

Corticosteroid injections into the scalp or topical corticosteroid creams and ointments can be used to deal with alopecia areata, as they suppress the immune system from attacking hair follicles. Immunotherapy involves the application of diphencyprone (DPCP) solution onto the scalp, and ultraviolet light therapy involves shining UVA or UVB rays on the scalp. These all have variable results and side effects. Often alopecia areata can be a temporary form of hair loss that does not require treatment. If it's permanent and does not respond to these treatments, then hair can be surgically implanted into the scalp.

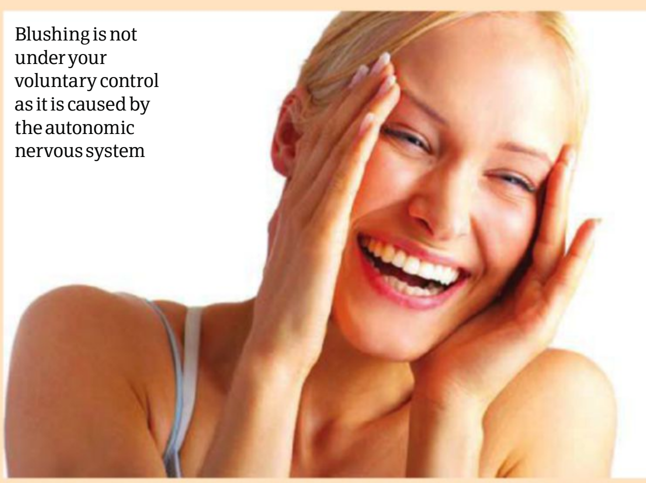
Blushing explained

What causes us to become flushed and red-faced?

Blushing occurs when you are in a state of excitement, anger or embarrassment. Children and young people are more prone to blushing and some people easily and frequently blush when they are confronted by stressful situations. Unfortunately, the fear of blushing (erythrophobia) causes even more embarrassment and blushing.

Blushing is not under your voluntary control as it is caused by the autonomic nervous system that controls the muscles of the blood vessels of your face. In an embarrassing situation your body releases adrenaline as part of the fight or flight response. This hormone triggers the blood vessels to dilate, and the increased blood flow in your cheeks makes your face red.

Besides our emotional state, high temperatures, alcohol and certain illnesses and medications can also cause us to have flushed faces.



Blushing is not under your voluntary control as it is caused by the autonomic nervous system

Yeast

Find out why the tiny yeast cell is essential for making bread, beer and wine

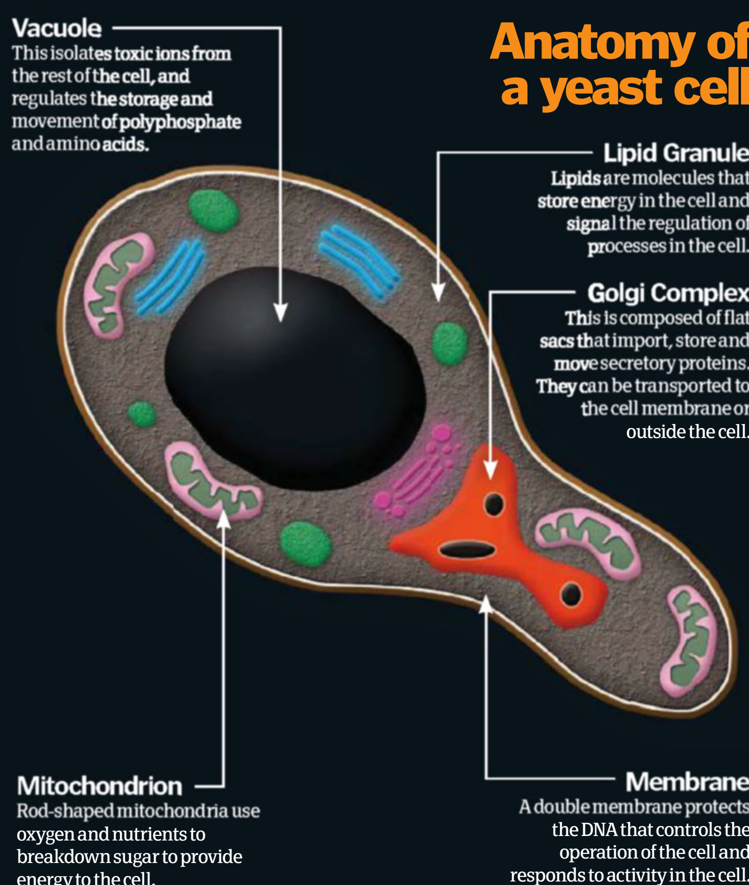
Yeasts are unicellular organisms that are members of the fungus family. There are thousands of different yeast organisms, but only a fraction of them have been studied in any detail.

They thrive on oxygen and carbohydrates, such as sugar, which causes them to produce ethyl alcohol and carbon dioxide. These processes are known as fermentation and anaerobic respiration.

Yeast cells are a type of eukaryotic cell that mainly multiply through the process of budding. A daughter cell forms on the side of the mother cell and in 20 minutes it swells and separates. During this process, the daughter cell can multiply in the same manner – even as it is still growing.

The saccharomyces cerevisiae strain of yeast is used for brewing and baking. In wine making, yeast converts the sugar in grapes into alcohol. In bread making, as yeast is mixed with the ingredients it is starved of oxygen and its reproduction is reduced, which then causes it to convert sugars in the dough into alcohol and carbon dioxide. This makes the bread dough rise and provides it with flavour.

Yeast is also used in the biotechnology industry to convert the sugars in cereal grains, sugar cane, paper and wood chippings into alcohol that can be used as a fuel instead of petrol or diesel.



Antiperspirants explained

The science behind sweet-smelling and sweat-free skin

Antiperspirants are deodorants that as well as masking body odour, also slow the rate of sweat excretion. Today, antiperspirants are typically sold in a rollerball applicator and are solid substances comprising several ingredients, including an aluminium-based compound, wax, liquid emollients and natural scent enhancers. The key to the sweat-blocking power, however, rests purely in the active aluminium-based compound that, in a typical commercial antiperspirant, makes up 10-25 per cent of the ingredients.

Ions of this compound – examples of which include aluminium chlorohydrate and aluminium chloride – are withdrawn into the cells that line the human body's eccrine gland ducts. The eccrine glands are responsible for producing the majority of the body's sweat and are located en masse in the armpits. As the compound's ions are absorbed into the ducts, they carry water with them, causing the ducts to bulge and swell to a level which forces them shut.

As a consequence of this process, any sweat is directly blocked from being excreted through the skin as it normally would.

Once the eccrine ducts have been closed, the other odour-reducing/masking ingredients then provide a thin coating to the skin's top layer. The gland ducts will remain closed until the water content both outside and inside the gland cells reaches equilibrium – the cells can only absorb a fixed quantity of water – and the cell content then begins to pass back out through osmosis. Typically antiperspirants are designed to last for a period of hours, before a top-up is needed.

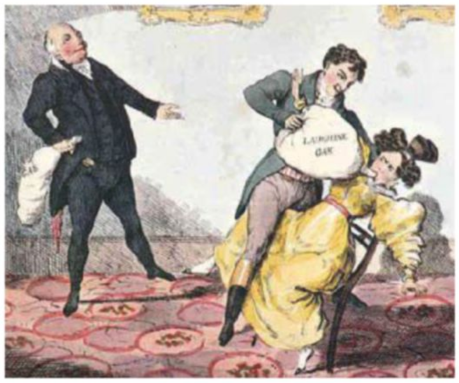
Rollerball antiperspirant applicators first appeared on the market in the Fifties

How laughing gas works

Why does this versatile gas leave us with the giggles?

Laughing gas – or nitrous oxide – is a colourless gas with a sweet odour and taste. Its principle use is as an anaesthetic in surgical operations, however due to its unique properties, it has been used for other non-medical purposes too. Its use as a stimulant – from which it acquired its name – grants the inhaler a short period of insensibility to pain, euphoria and a tendency to mild hysteria (ie laughter). The gas has this effect as it both modulates a broad range of ligand-gated ion channels in the user's nervous system and partially/fully inhibits NMDAR-mediated currents (the NMDA receptor is the brain's predominant molecular device for controlling synaptic plasticity and memory function).

Importantly, however, while nitrous oxide is still sold and used for recreational purposes, scientific trials have discovered that it does in fact cause neurotoxic damage to the posterior cingulate and retrosplenial cortices of the brain (areas involved with awareness and memory), and that prolonged use will actually lead to death.



This is an early 19th-century cartoon of a Royal Institution chemistry lecture where the effects of nitrous oxide are demonstrated. Here the gas has led to one of the experimenters losing his inhibitions in the first stage of anaesthesia

Nitrous oxide is also used as a performance enhancer in combustion engines

© Xavier Rincker

A primary contributor of carbon monoxide to the atmosphere is vehicle emissions

Carbon monoxide

Why is this invisible and odourless gas so deadly?

Carbon monoxide poisoning is the most common form of fatal air poisoning. Colourless, odourless and tasteless, carbon monoxide is so deadly as it is adept at binding with haemoglobin in the blood. On doing this it produces carboxyhaemoglobin, which – unlike haemoglobin – is completely ineffective in carrying oxygen to bodily tissues.

While carbon monoxide is itself difficult to detect, carbon monoxide poisoning in humans can be seen through the colouration of the skin and lips. This is because carboxyhaemoglobin has a characteristic cherry-red colour and, in large concentrations, causes pigmentation in the skin. Other indications of carbon monoxide poisoning include headaches, dizziness and a weak pulse. One of the biggest contributors of carbon monoxide to the environment is exhaust fumes from combustion engines.

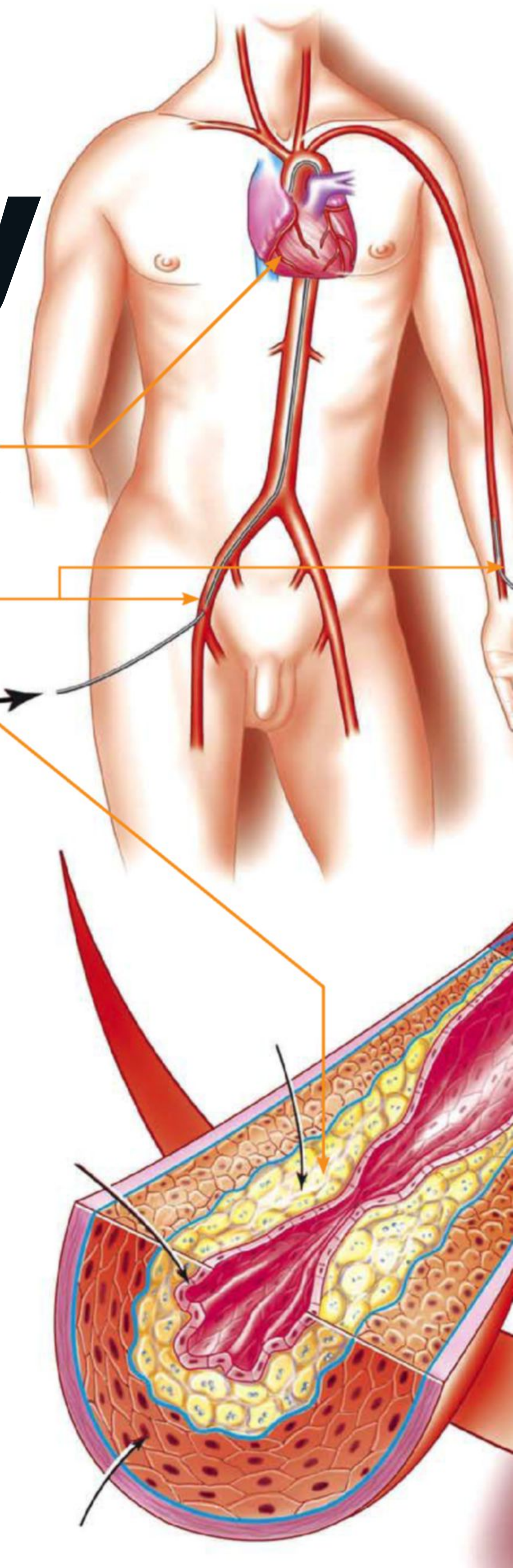
How does angioplasty work?

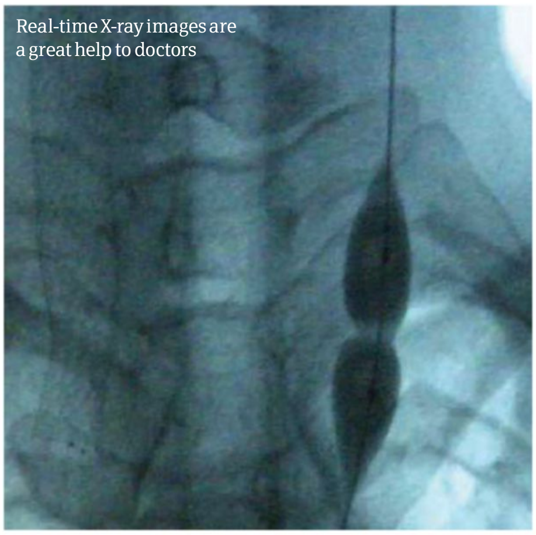
Angioplasty is a cutting-edge medical procedure that helps your heart last longer

Your heart pumps blood-rich oxygen to your body's tissues – but the heart muscle needs oxygen itself. The coronary arteries are small vessels lining your heart's surface that do this job perfectly, in exact synchronisation with the beats of the heart. However, they can become blocked. A lack of exercise, smoking, poor diet and unlucky genes can all lead to plaques of fatty tissue, called atheroma, blocking these vital arteries. Then, if your heart needs to pump harder, such as during exercise, the reduced blood flow cannot supply enough oxygen. This leads to pain – angina – which is an early warning sign that the heart muscle is dying. Previously, the only way to cure advanced cases was to go under the surgeon's knife. However, cardiac surgery is a risky procedure. Then along came angioplasty.

Via a small artery in the patient's groin or wrist, doctors insert a guide wire directly into the coronary arteries of the heart. This is tricky, and so they use real-time X-ray images to guide them to exactly the right place. They feed a tiny, thin, flexible hollow tube over this wire (a catheter). Injecting dye into these arteries (via the hollow catheters) and looking carefully at the result shows them exactly where the blockages are. Next, they inflate tiny balloons attached to the end of these long catheters at the exact spot of the blockage. In some cases, this is enough. In others, to prevent the artery closing again, a stent can be placed through the affected area. These are clever stents and can contain drugs that prevent them blocking. A final check X-ray completes the angioplasty process.

Angioplasties like this can also be performed on blocked arteries in the legs, where the principle is exactly the same. But no matter where the blockage is, this procedure requires a steady hand and a doctor who can think fast and think in real-time 3D while looking at 2D black-and-white images.




Real-time X-ray images are a great help to doctors

The procedure

Angioplasty is one of the most commonly performed medical procedures around the world – there's a good chance that you know someone who's had one. However, the procedure still requires a lot of technical skill and a steady hand. Even in the best hands there are risks and complications, but most people get good results from it.

5 TOP FACTS ANGIOPLASTY

Drug eluting

1 The most modern stents that are used in angioplasty procedures aren't just bare metal, some also secrete drugs over time, which work to prevent a blockage.

No napping

2 In the modern era, angioplasty patients stay awake during the entire procedure, as it is now performed with the patient under local anaesthetic.

High tech all the way

3 Once the ballooning and stenting is done, the tech doesn't stop. There are devices to close holes made in the groin or wrist arteries to stop them getting bigger.

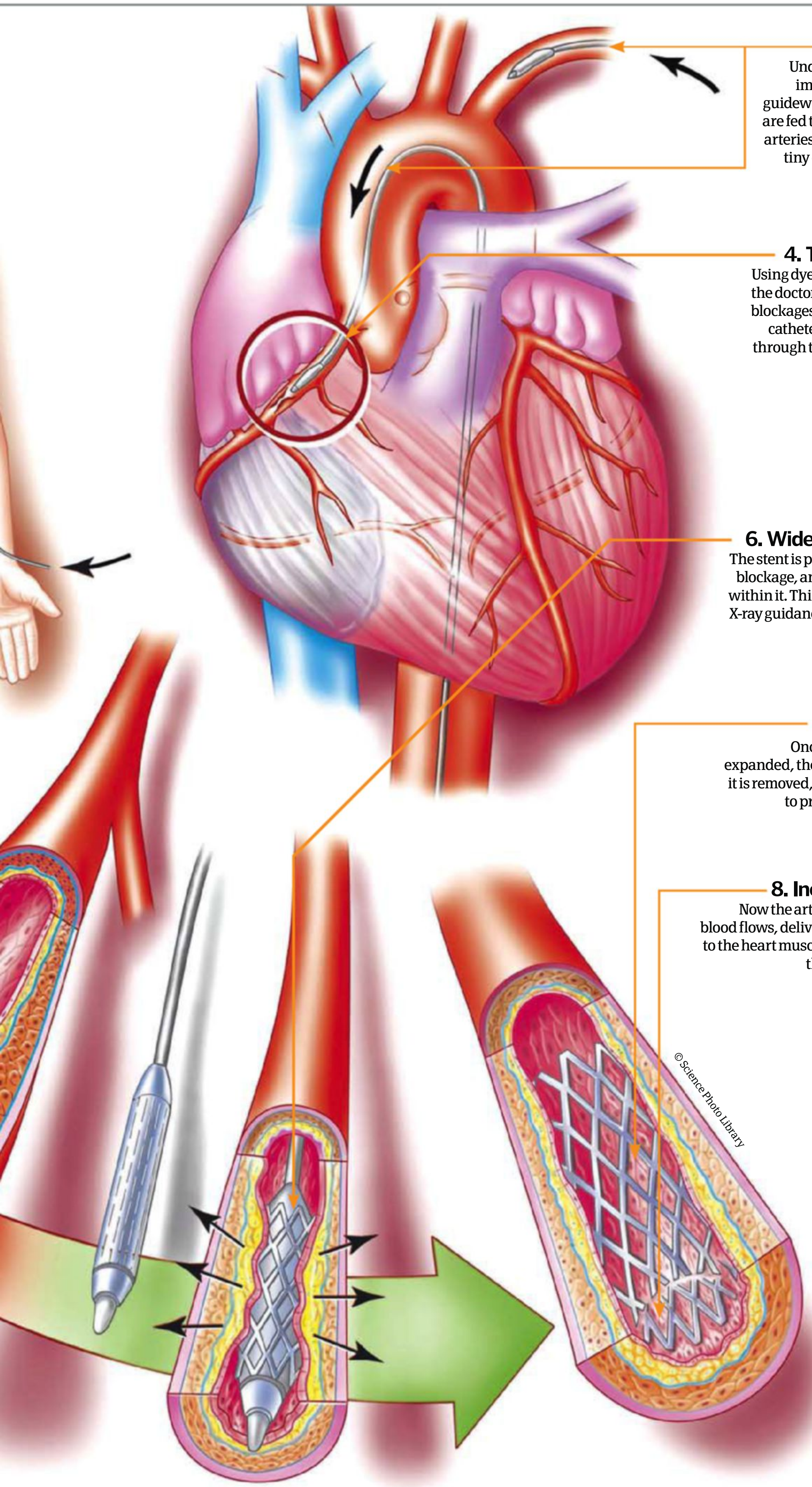
All the way up?

4 Although an angioplasty is mainly used on coronary arteries, there are some doctors trialing angioplasty for narrowed arteries that feed blood to the brain.

Lasers

5 Recent angioplasty-related technological developments include using lasers at the end of the catheters to burn away the offending plaques.

DID YOU KNOW? [illegible] age, race and gender of a skeleton



3. X-rays
Under real-time X-ray image guidance, the guidewires and catheters are fed through the major arteries and then into the tiny coronary arteries.

4. The blockage
Using dyes, the X-rays show the doctors where the exact blockages are, and then the catheters are introduced through these narrowings.

6. Widening the gap
The stent is placed through the blockage, and then expanded within it. This is all done under X-ray guidance so it's in exactly the right position.

7. The stent
Once the stent is fully expanded, the catheter holding it is removed, leaving it in place to prevent reblockage.

8. Increased flow
Now the artery is wider, more blood flows, delivering vital oxygen to the heart muscle and preventing the pain of angina.

It all started 300 years ago… on a horse

From a single horse to the whole world

The first angioplasty of the heart was carried out in the 18th Century on a horse. It took a while to perfect it for humans, and in 1929 the first angioplasty on a person's heart was performed in Germany. Over the next 30 years a small number of doctors pioneered the angioplasty into a diagnostic and therapeutic technique. While in the Sixties and Seventies open heart surgery became established, in the Seventies and Eighties angioplasty started to take over as a lower risk but equally effective treatment. Astonishingly, in the late-Nineties, over 1 million angioplasties were performed worldwide, making it one of the most common medical procedures on the planet.

Balloon catheter

The balloon catheter is one of the key pieces of the angioplasty doctor's equipment. Once the guidewire is inserted, the catheter is fed over it and floated into exactly the right place. Through this catheter, special dyes that can be seen on X-ray images (radio-opaque contrast dye) can be injected through the hollow catheter to confirm its position and then confirm the location of the blockages.

At the tip of the catheter is a balloon. Using water, this balloon can be inflated from outside to precise pressures. When this is done from the centre of the blockage, the atheromatous plaque is expanded to allow more blood flow. There are many different sizes of catheter and widths of balloons, allowing exact tailoring to the patient's needs. Sometimes the doctor will start with a small balloon when the blockage is very narrow, and then sequentially insert larger balloons to allow for the maximum effect. However, care is needed – too large a balloon or too much pressure and the vessel can rupture, which is a life-threatening complication. Experience, care and control of the pressures prevent this.

How the shoulder joint works

Bones and muscles work in perfect harmony to enable the wide range of movement our arms enjoy

Bones are like levers: this was the conclusion drawn by Italian physician, Giovanni Alfonso Borelli, when he was studying the human skeleton to see how it worked in the 17th century. He applied mechanical principles, showing that bones and joints work as levers, powered by muscles.

Today, we have a much more detailed understanding of how the body works, and the shoulder joint is a particularly interesting and complex arrangement, comprising the upper arm bone (humerus), the shoulder blade (scapula) and the collar bone (clavicle) – the last two of which form the roof of the shoulder.

The shoulder has three joints that work together to allow arm movement; the main one is the glenohumeral joint, a synovial ball and socket type. The rounded head of one bone fits into the cup-like cavity of another. This allows the greatest range of movement of any joint in the human body.

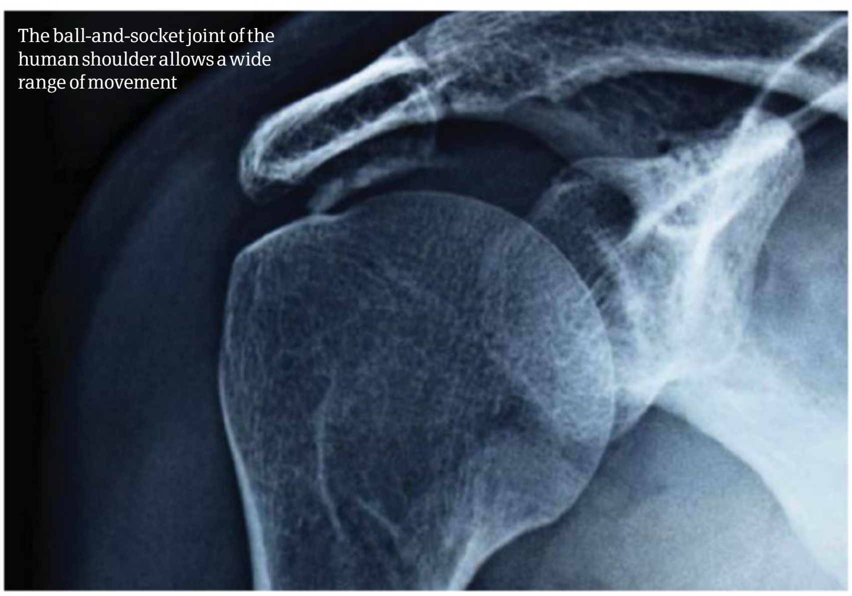
The others are called the scapulothoracic joint (between the shoulder blade and ribs), and the acromioclavicular joint (between the shoulder blade and the collar bone). Raising the arm above the head requires all three of these to work in unison.

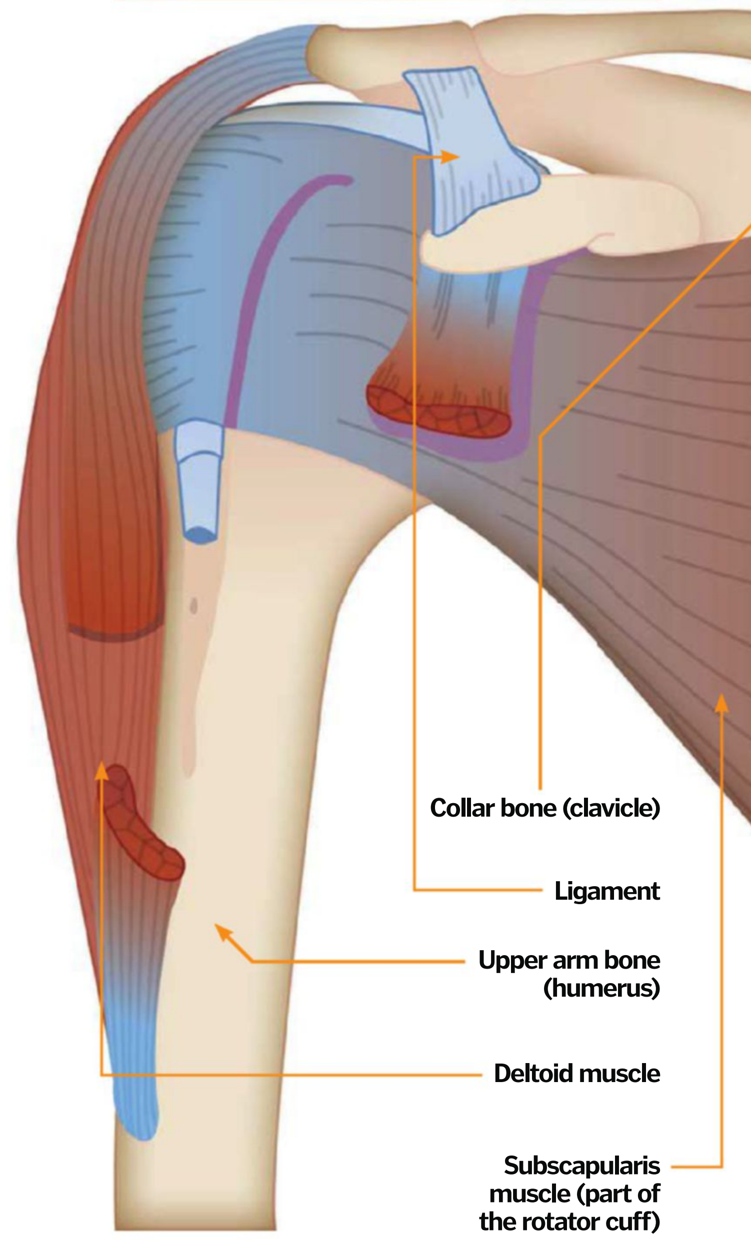
Meanwhile, the deltoid muscle, which covers the shoulder joint, plays an important role in raising the upper arm. Nerve impulses cause the fibres in the anterior and posterior parts of the muscle to balance, while the fibres in the middle contract to draw the arm upwards.

A group of four muscles pull the humerus into the shoulder blade. Together, they are called the rotator cuff, and they stabilise the joint and aid arm rotation. The subscapularis muscle is a part of the rotator cuff and enables your arm to turn inwards.

Within the joint, the ends of the bones are covered by articular cartilage, which cushions them as they move and generally acts as a shock absorber. The whole joint is encased in a fibrous capsule which helps to provide structural integrity. The capsule contains the synovial membrane, a soft tissue that secretes thick synovial fluid into the joint, to nourish the cartilage and keep it slippery.


Such a complex part of the body is prone to injuries, from dislocation to frozen shoulder syndrome


The ball-and-socket joint of the human shoulder allows a wide range of movement



5 TOP FACTS
GEN UP ON JOINTS

A bodybuilder's favourite
1 The pectoralis major is a large muscle spanning the front of the chest. It plays a role in movement of the shoulder joint, enabling medial rotation, as well as throwing and lifting.

Shoulder power
2 The strength of the shoulder is a combination of bone density and muscle power. Compared to the hip, there is less bone integrity as the shoulder bones are much shallower.

Joint pain
3 People whose joints are causing them pain can sometimes find relief by taking glucosamine and/or chondroitin tablets, or by swallowing fish oil capsules.

Cartilage care
4 Cartilage is made of collagen and elastin. Vitamin C aids in the formation of collagen in your body, while copper can have a positive effect on the formation of elastin.

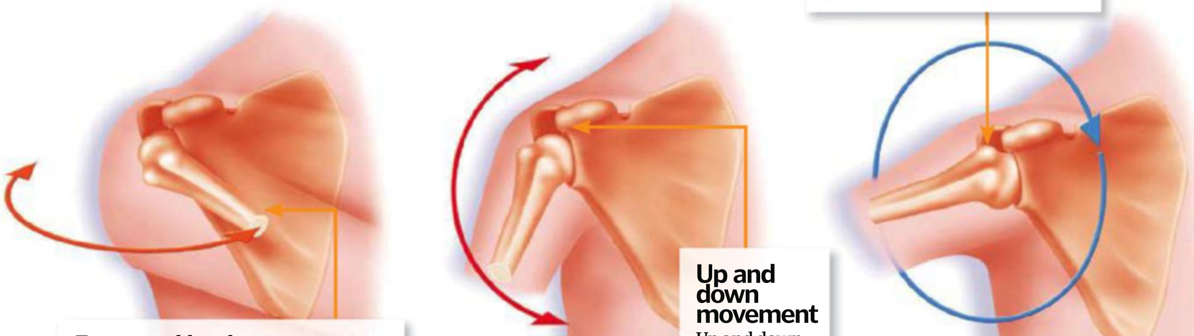
Happy bones
5 Everyone knows calcium is important for bones, but for calcium to be utilised properly, vitamin D is essential – a 20-minute spell in the Sun will boost your vitamin D levels.

DID YOU KNOW? *The shoulder blade is not connected to your ribcage but is held in place by fibrous muscle tissue*

The ball and socket joint

This joint enables greater movement than any other in the human body

Full circle
You can do a complete circle with this kind of joint – something not possible with any other joint.



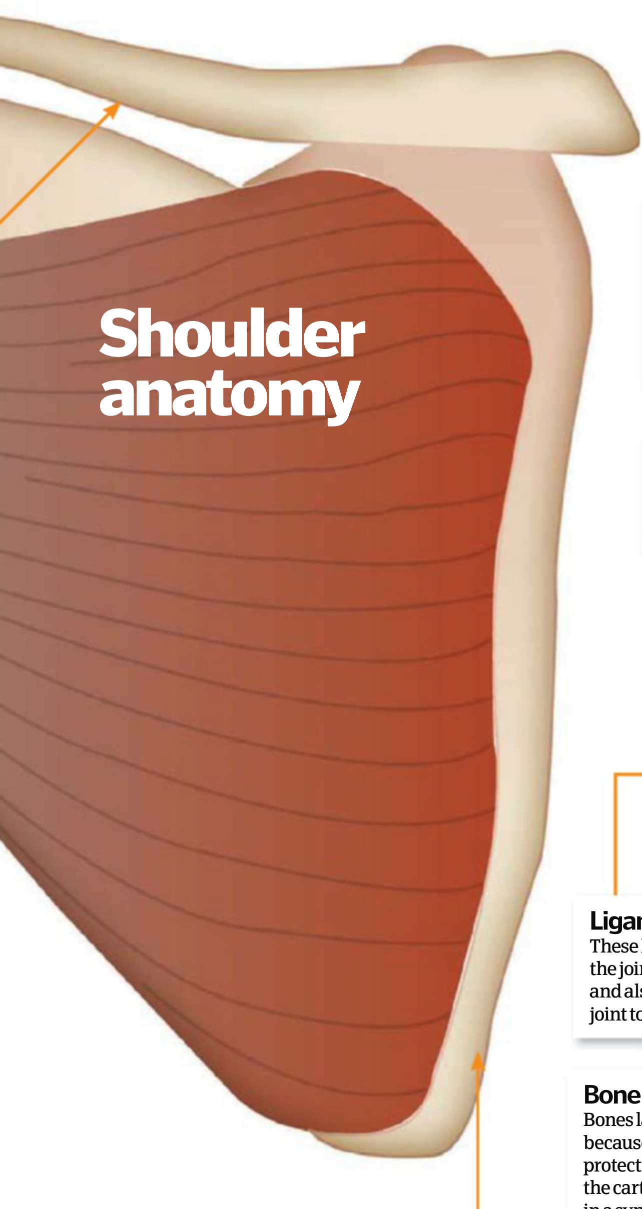
Front and back movement
The joint enables you to swing your arm comfortably from front to back.

Up and down movement
Up and down movements are just as easy.

Dislocation

A shoulder dislocation occurs when there is an injury to the joint between the humerus and shoulder blade. The wide range of motion allowed means the glenohumeral joint is not as stable as other joints in the body, making shoulder dislocation relatively common. Such an injury usually occurs after a sporting fall, and often the humerus is found sitting in front of the shoulder blade (an anterior dislocation). Just five per cent of dislocations are posterior dislocations where the humerus is behind the shoulder. Dislocation is extremely painful because it stretches the joint capsule and ligaments, and everything is under huge pressure – there will probably be breaking of tissues and bleeding. Once diagnosed, bones can be put back in place by trained medical staff and anaesthesia is often provided to reduce the pain.

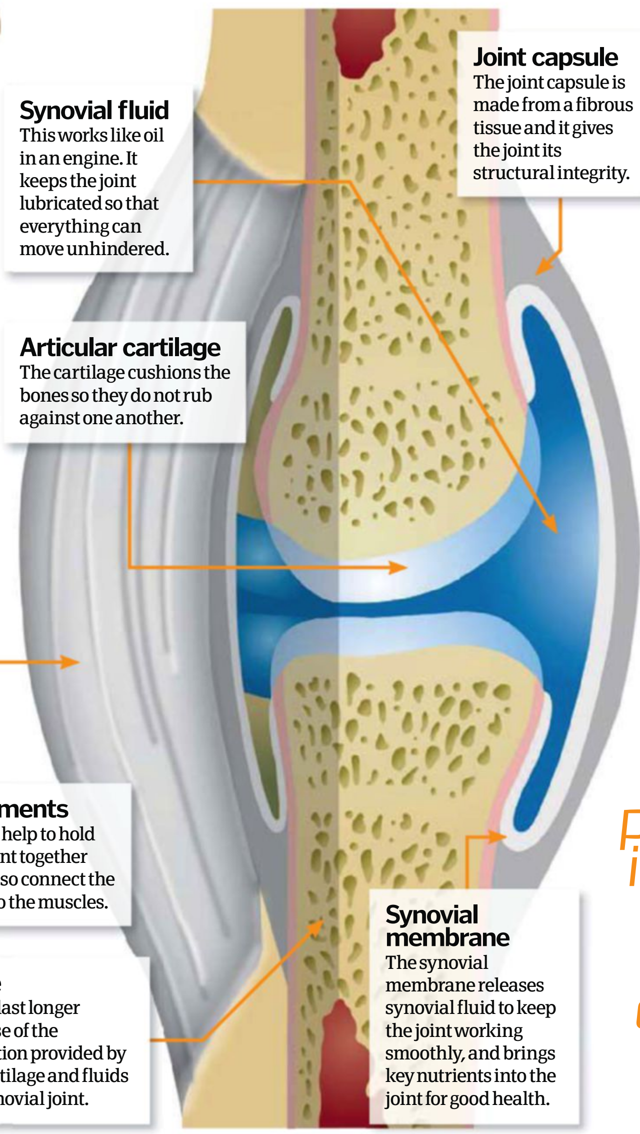
Shoulder anatomy



Shoulder blade (scapula)

Synovial joint

A synovial joint contains synovial fluid released from a special membrane, all held together within a joint capsule



Synovial fluid
This works like oil in an engine. It keeps the joint lubricated so that everything can move unhindered.

Joint capsule
The joint capsule is made from a fibrous tissue and it gives the joint its structural integrity.

Articular cartilage
The cartilage cushions the bones so they do not rub against one another.

Ligaments
These help to hold the joint together and also connect the joint to the muscles.

Bone
Bones last longer because of the protection provided by the cartilage and fluids in a synovial joint.

Synovial membrane
The synovial membrane releases synovial fluid to keep the joint working smoothly, and brings key nutrients into the joint for good health.

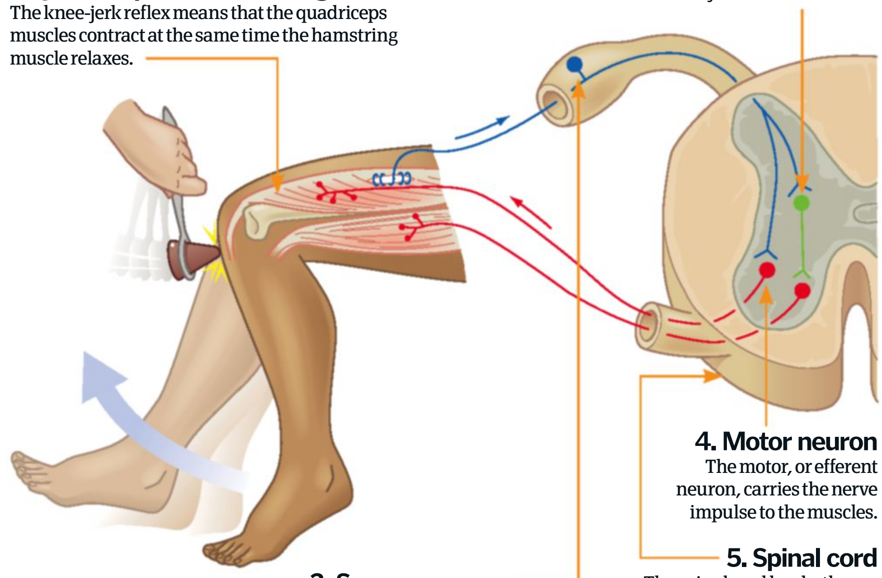
> "Dislocation is extremely painful because it stretches the joint capsule and ligaments, and everything is under huge pressure"

Knee-jerk reactions explained

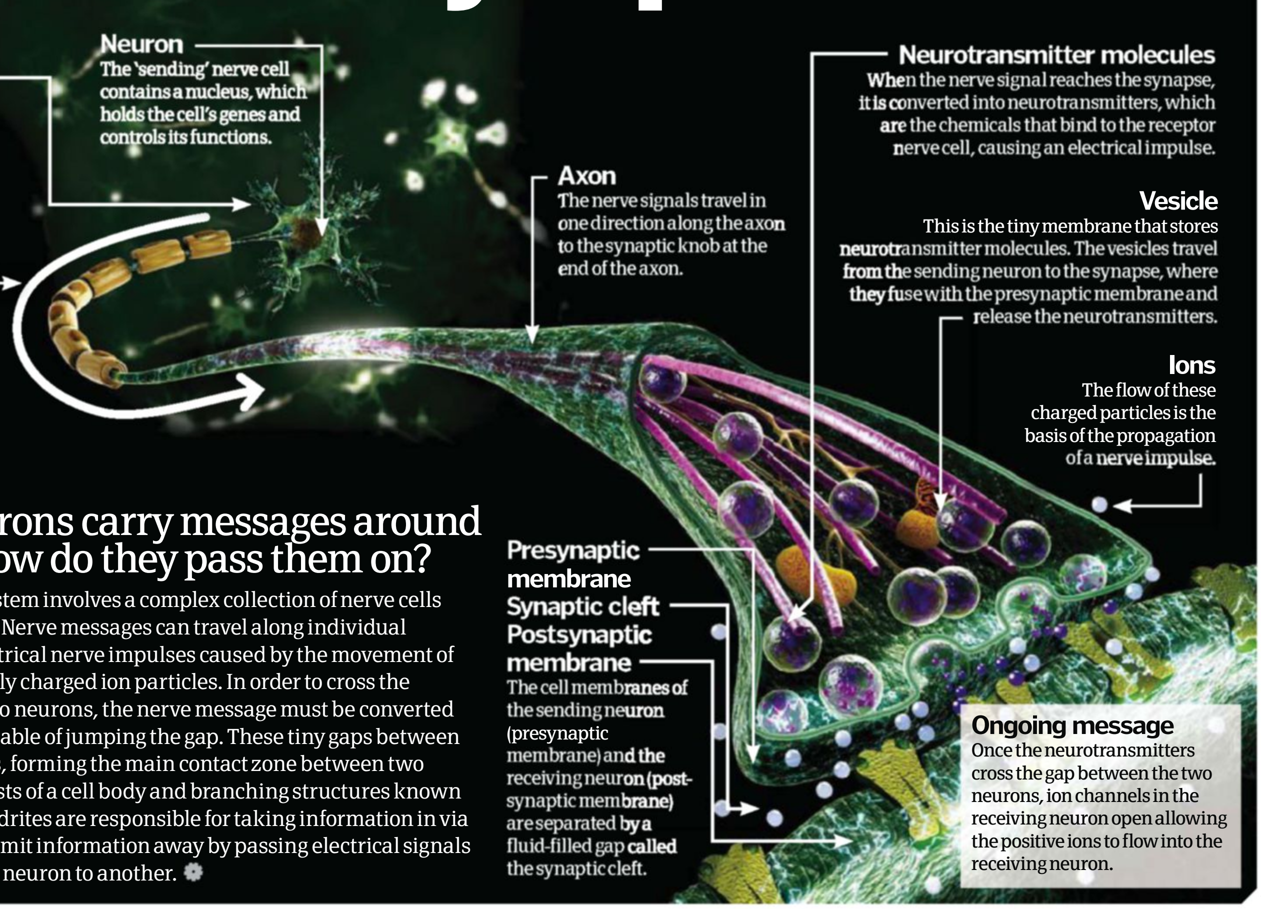
Why does your leg kick out when the doctor taps just below your knee?

Doctors often test the knee-jerk, or patellar reflex, to look for potential neurological problems. Lightly tapping your patellar tendon just below the kneecap stretches the femoral nerve located in your thigh, which in turn causes your thigh muscle (quadriceps) to contract and the lower leg to extend. When struck, impulses travel along a pathway in the dorsal root ganglion, a bundle of nerves in the L4 level of the spinal cord. Reflex actions are performed independently of the brain. This allows them to happen almost instantaneously – in about 50 milliseconds in the case of the knee-jerk reflex. This reflex helps you to maintain balance and posture when you walk, without having to think about every step you take.

The knee-jerk step-by-step



How does a synapse work?



Trillions of neurons carry messages around the body, but how do they pass them on?

The nervous system involves a complex collection of nerve cells called neurons. Nerve messages can travel along individual neurons as electrical nerve impulses caused by the movement of lots of electrically charged ion particles. In order to cross the minuscule gaps between two neurons, the nerve message must be converted into a chemical message capable of jumping the gap. These tiny gaps between neurons are called synapses, forming the main contact zone between two neurons. Each neuron consists of a cell body and branching structures known as axons and dendrites. Dendrites are responsible for taking information in via receptors, while axons transmit information away by passing electrical signals across the synapse from one neuron to another.

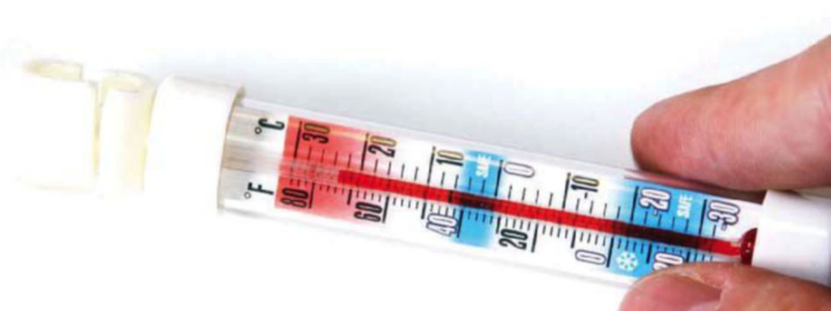
DHA-based lotions have no side effects

How does fake tan work?

Getting a tan without exposure to the Sun's harmful UV rays

Today, the majority of sunless tanning lotions, mousses, sprays and gels contain a safe sugar molecule called dihydroxyacetone (DHA), which darkens skin tone with no side effects.

The concentration of the DHA determines the darkness of the fake tan. DHA reacts with the amino acids present in dead cells on the surface of the skin to alter their colour, producing a yellow/brown tanned appearance. The colour doesn't come through straight away, however; it develops over a number of hours and often keeps getting darker for 24 hours. Further application of the tanning lotion over a number of days will create a darker tone. Because the tan only affects the already-dead surface skin cells, the colour will of course fade and wear off as the skin is eventually shed.



How thermometers work

How does this household device reveal the temperature?

Traditional thermometers contained mercury, which expands with rising temperatures. Most households now have digital thermometers, as they're safer, easier to read, and work faster. Digital thermometers contain an electric resistor, also known as a thermistor, which is temperature-sensitive. When the temperature rises, the thermistor becomes more conductive. This happens at about 37°C (99°F). A microcomputer pinpoints the temperature by measuring the conductivity, and displays it on an LCD screen.

Originally, Anders Celsius pegged his scale with the boiling point of water at 0 degrees and the freezing point of ice at 100 degrees, based on the water's behaviour under pressure, but Carl Linnaeus swapped these after his death.

Daniel Gabriel Fahrenheit first based his scale on three states of brine, which were stable, freezing and boiling. Later his scale was adjusted so there were 180 intervals between the freezing point of ice (32°F) and boiling point of water (212°F). The scales intersect at -40 degrees.

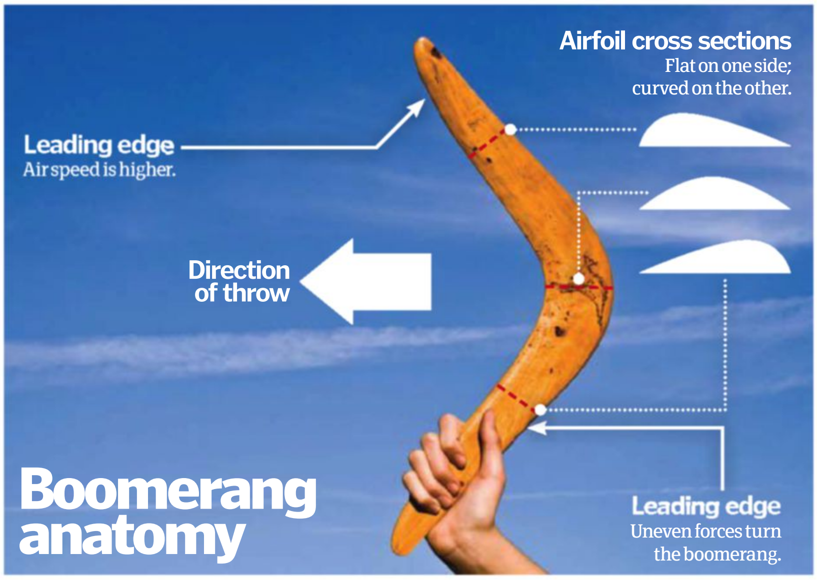
The science of boomerangs

Learn the principles that make this flying stick come back

A boomerang is basically a single-winged aircraft propelled through the air by hand. Boomerangs have two 'wings' joined in a V-shape. Both wings have an airfoil-shaped cross-section just like an aircraft wing. An airfoil is flat on one side but curved on the other with one edge thicker than the other – this helps the boomerang stay in the air due to lift.

Lift is generated as the air flowing up over the curved side of the wing has further to travel than the air flowing past the flat side. The air moving over the curved surface must therefore travel quicker in order to reach the other edge of the wing.

Because the two sides of a boomerang have different air speeds flowing over them, as it spins the aerodynamic forces acting upon it are uneven. This causes the section of the boomerang moving in the same direction as the direction of forward motion to move faster through the air than the section moving in the opposite direction. These uneven forces make the boomerang start to turn in and follow a circular route, eventually heading back to the thrower.



The ageing process

What happens to the human body as we age

The whys of ageing, at its most basic level, seem simple: over the course of our lives, our bodies simply wear out. Or that's what we've been led to believe, anyway. Scientists who study gerontology, or the process of ageing, don't yet have a definitive answer as to why we age. There are two schools of thought. The wear-and-tear concept – meaning our cells are used up over time – that many subscribe to is just one example of an error theory.

Proponents of the error theory believe that random external events cause damage that builds up in our bodies over the course of our lifetime until our cells can no longer function. Free radicals – unstable oxygen molecules that are a natural by-product of cell function – can build up and bond to other cells. As a result, DNA can be damaged. They may also result in protein cross-linking, or glycosylation, a phenomenon by which protein molecules in our bodies inappropriately bond together. They aren't as elastic and don't move or break down like they're supposed to.

Evidence for this theory is wrinkles, for example, caused by a breakdown of collagen, a type of protein found in the skin. Protein cross-linking may also be responsible for a lot of infirmities associated with ageing that have to do with stiffening or hardening of tissues, such as atherosclerosis.

Cells can also mutate on a genetic level due to environmental or other factors. Problems with

5 TOP FACTS SIGNS OF AGEING

Grey hair
1 When your hair turns grey has a lot to do with your genetics, but the loss of melanin associated with grey hair is due to older age.

Wrinkles
2 The loss of skin elasticity also ages us through the creation of wrinkles, although in some cases it can be prevented or at least slowed down.

Missing teeth
3 Enamel on our teeth wears down over time and maintaining dental hygiene becomes more difficult, resulting in tooth loss.

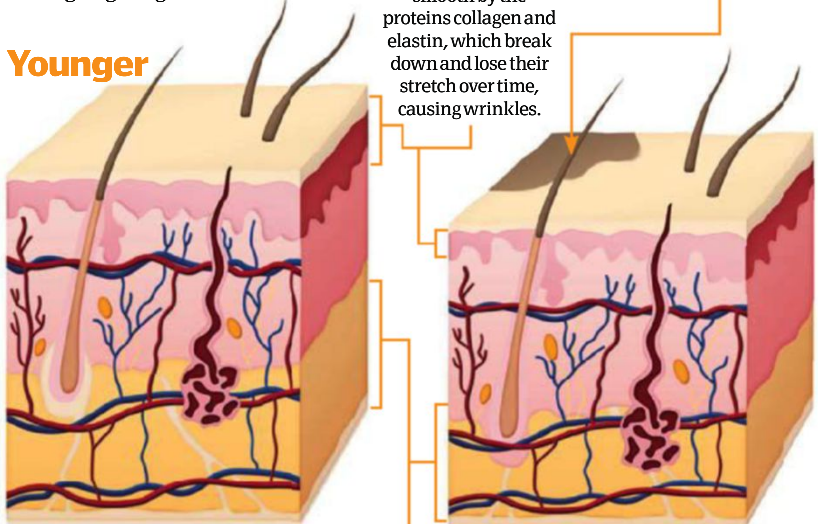
Loss of eyesight
4 With ageing can come a number of vision problems that can cause a loss of sight, including cataracts, glaucoma and macular degeneration.

Loss of hearing
5 Age-related hearing loss can be caused by everything from environmental factors to a degeneration of the fine hair cells in the cochlea.

DID YOU KNOW? The process of ageing by a living system, or organism, is known as organismal senescence

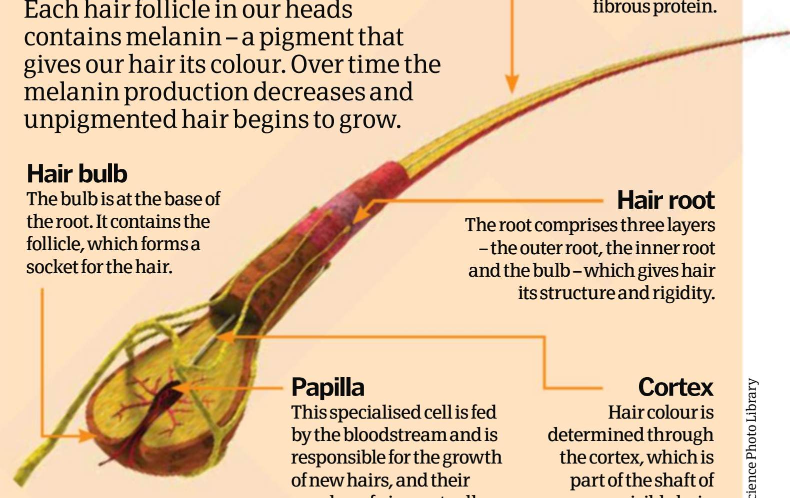
Ageing skin

What looks like spots and wrinkles is actually a number of changes going on under the skin.

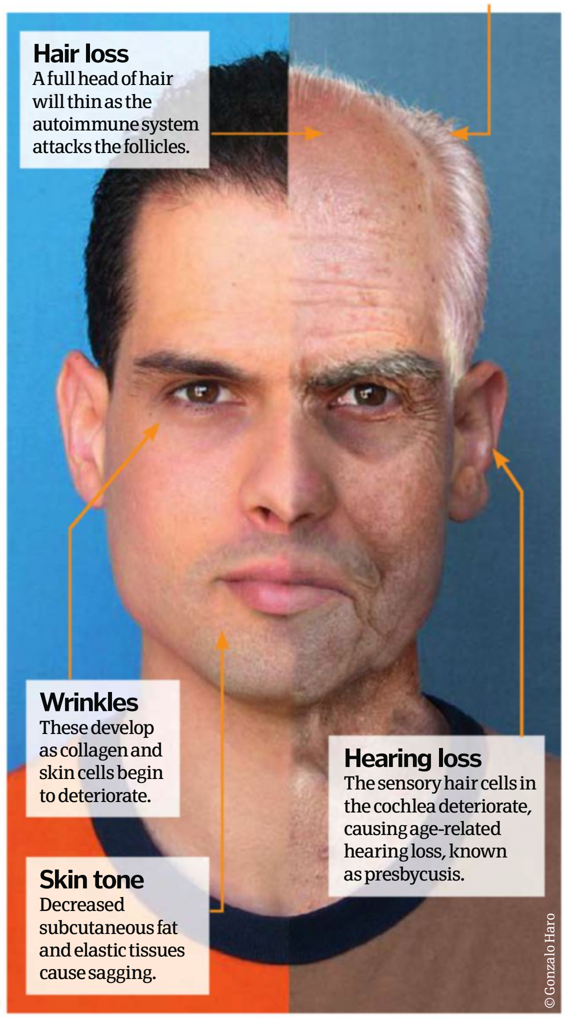


Going grey

Each hair follicle in our heads contains melanin – a pigment that gives our hair its colour. Over time the melanin production decreases and unpigmented hair begins to grow.



Signs of ageing



> "Although our genes play a part in our life span, they can be influenced or changed"

mitochondria, structures that provide energy inside cells, can cause cells to die as well as diseases associated with old age such as Alzheimer's disease.

Another group of theories puts forth the idea that our life spans are predetermined or programmed. One scenario suggests that the biological clock is 'set' by both our neuroendocrine system, which produces hormones, and our immune system. The hypothalamus in the brain sends messages via hormones to the pituitary gland, which in turn stimulates or restricts hormone secretions by the thyroid, adrenal glands, ovaries and testicles.

Over time this complex system does not function as efficiently, leading to everything from problems sleeping to menopause (which is a normal part of ageing for women, but can in fact lead to additional health problems).

Different types of cells in the immune system decline in number as we age and do not function as well. Some scientists point to the fact that the overall risk of contracting cancers goes up as we get older; younger, more efficient immune systems may have been able to fend them off.

Or it could all simply be genetic. That is, our DNA tells our bodies when life is at an end. There does seem to be a genetic component to ageing among most animals – they have predictable life spans. Women also tend to live a little longer than men. If your parents lived for a long time, you are more likely to do so yourself. One group of genes, known as the longevity assurance gene, ha been determined to influence life span. If you inherit the 'helpful' version then you are more likely to have a longer life.

Although our genes play a part in our life span, obviously they can be influenced or changed. Otherwise, we'd still be living to the ripe old age of 30 instead of 80 (the average life span in developed countries). Most researchers believe that ageing is a complex process that no single theory can explain – it's a combination of our genes, our biological functions and environmental factors.

We tend to focus more on the visible signs of ageing at first, like wrinkles and grey hairs, and these changes are prime examples of how complicated the process can be. We've already talked a bit about the cause of wrinkles: the connective tissues collagen and elastin, that keep skin looking smooth, both break down over time. Without the firm connections underneath, the skin sags. Many people lose fat deposits in their faces, and the skin's oil production decreases. Many of these things have a genetic component, but outside factors such as exposure to ultraviolet radiation and smoking both cause wrinkles and sags faster. The Sun's rays break down connective tissues, while smoking causes blood vessels to contract.

Grey hair is caused by a loss of melanin, the pigment that is responsible for our hair colour. Only recently have scientists learned that melanin production gets interrupted when hydrogen peroxide levels in the body increase over time. Other proteins found in hair cells that are responsible for regrowth diminish over time too. ▶

Unlike with wrinkles, however, there isn't much you can do to avoid going grey other than dye your hair. Genetics do seem to play a part, though. If your parents went grey at a young age, you likely will too.

The internal signs of ageing are more serious, health-wise, than the external ones. When and how they occur are also based on a wide variety of factors. Some gerontologists like to generalise that some parts of the body get harder as we age, while others get softer, but everything is interconnected. As we mentioned before, arteries get harder due to a buildup of plaque. The heart builds up pressure because it has to work more to pump blood through the harder, narrower blood vessels, which results in high blood pressure. Other muscles, like the lungs, get harder due to calcium deposits. These can be caused by hormonal changes or from having serious infections such as tuberculosis.

Meanwhile, hormonal changes cause calcium to leech from the bones, making them soft and brittle and reducing their density. Known as osteoporosis, this loss means that we're at a greater risk of breaking bones. Sarcopenia, or loss of muscle mass, is another 'soft' sign of ageing. Muscles contain special cells called satellites, a form of stem cell. These cells are responsible for muscle growth as well as regeneration when there's some form of damage. These cells gradually become less proficient over time, possibly due to a corresponding decrease in growth factors (hormones or proteins that stimulate cell growth). Loss of tone in muscles such as the anal sphincter and the bladder can cause one of the most embarrassing signs of ageing for many people: incontinence.

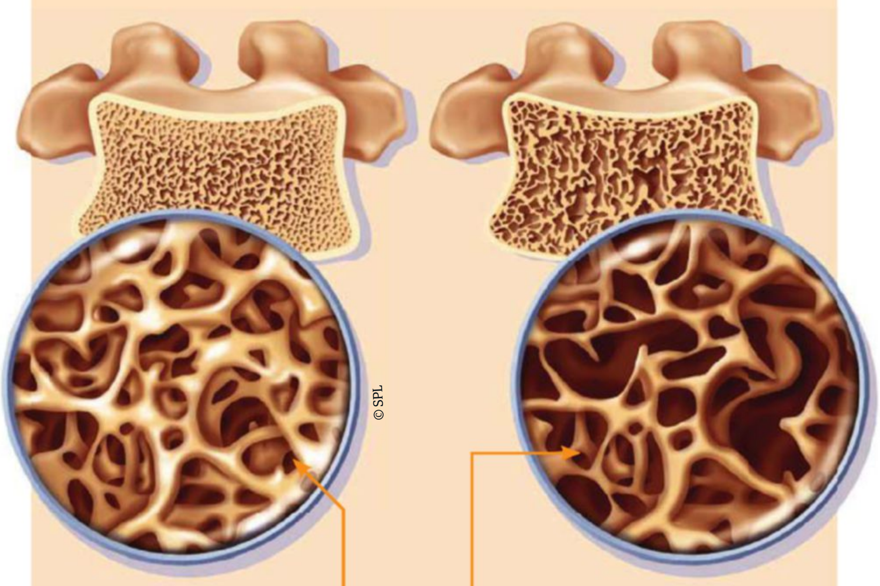
The ageing brain is still very mysterious compared with what we know about the rest of the body. It was once thought that age-related issues such as memory loss had to do with a decrease in neurons. Now, however, researchers believe that unless you have a specific disease that damages neurons, complex chemical processes are more likely to blame. For example, the brains of people with Alzheimer's disease tend to have deposits of fibrous proteins called amyloids. The exact cause is unknown, although one theory is that the amyloids manage to get into the brain because the system that regulates the exchange of blood in the brain, known as the blood-brain barrier, malfunctions.

What's most fascinating about the ageing process is that it's different for everyone and it is unpredictable in so many ways. Thanks to the advances being made in medicine, we're learning more every day about not only what causes the most unpleasant signs of ageing, but also what we are able to do in order to counteract them.

Bone loss

A condition that affects ageing bones

Osteoporosis is a degenerative bone disease that results in lower bone density, which makes the bones weak and fragile. The risk of falling as well as breaking bones increases as the disease worsens. It is caused by a loss of the minerals that make up bone, such as calcium. There is a genetic factor, and the decrease of sex hormones in both genders increase the likelihood of developing osteoporosis.

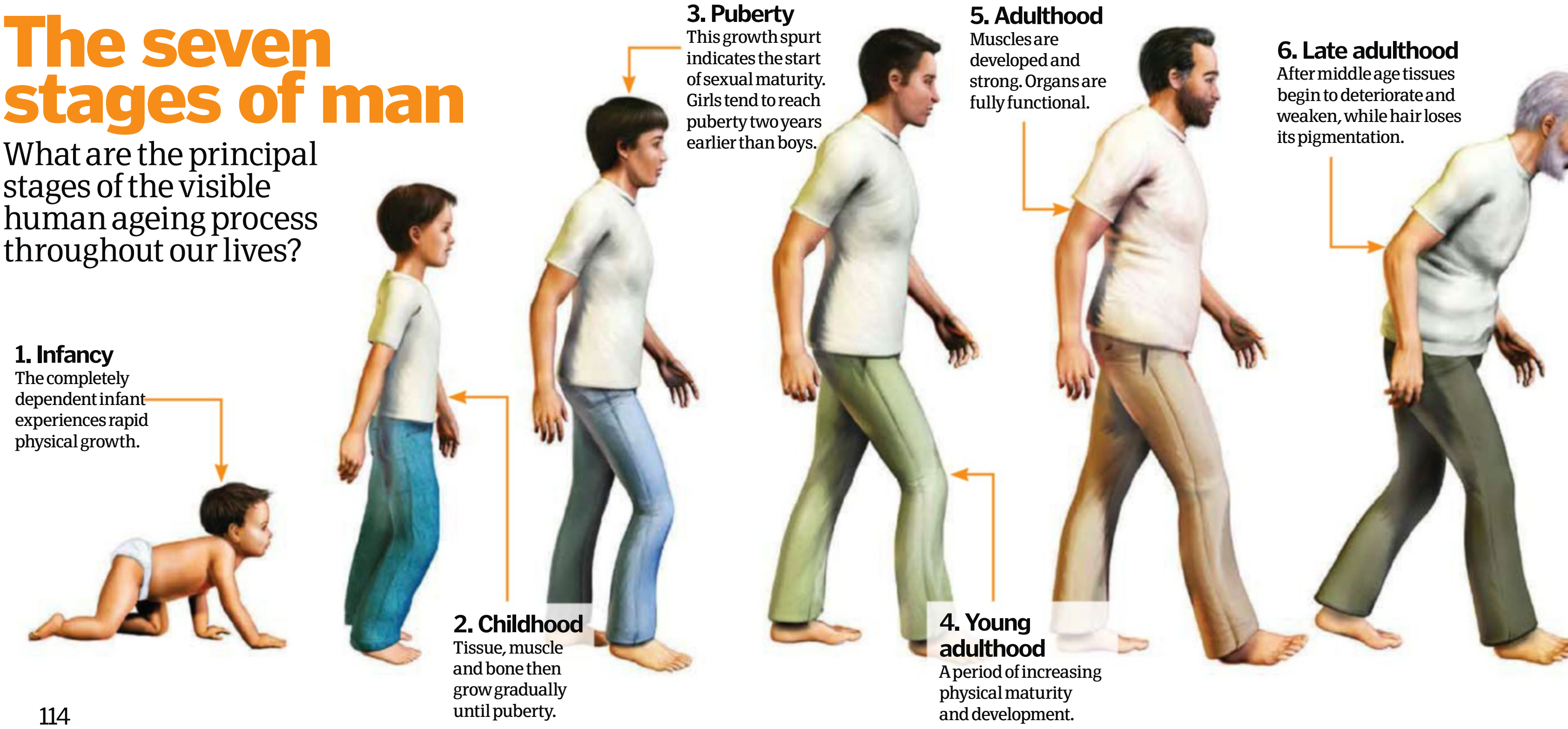


1. Healthy bone
Healthy bones contain tight, strong structures and are able to easily bear body weight in most circumstances.

2. Bone with osteoporosis
Bones with osteoporosis have gapped, porous structures. They are fragile and can fracture easily, as well as lead to falls.

The seven stages of man

What are the principal stages of the visible human ageing process throughout our lives?



Head to Head
WAYS TO BEAT AGEING

DRASTIC

1. Nutritional changes
Antioxidants such as vitamin E and calorie-restrictive diets have both been shown to extend life span, but not without potential health risks.

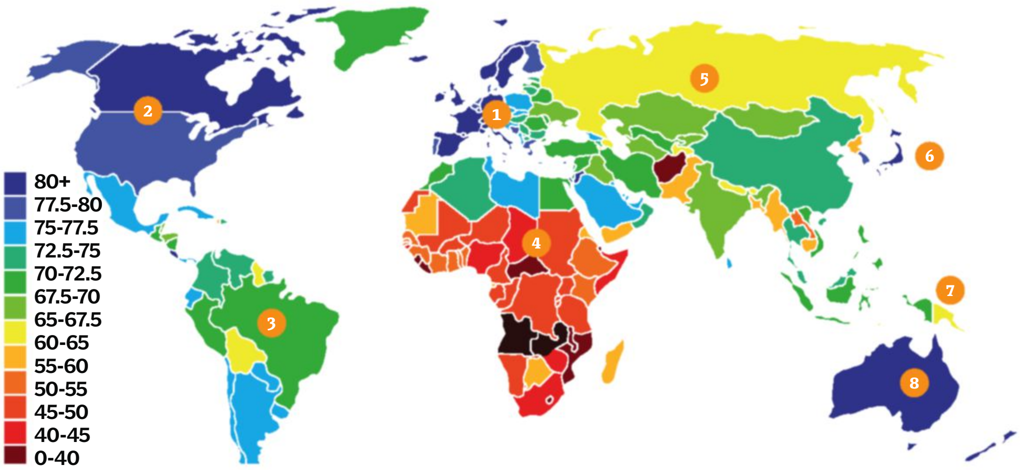
MORE DRASTIC

2. Hormone therapy
The use of hormones such as human growth hormone to combat signs of ageing, such as decreased muscle mass, is very controversial.

MOST DRASTIC

3. Plastic surgery
The visible signs of ageing can be combated – temporarily – through surgery and other cosmetic procedures.

DID YOU KNOW? Ageing changes can be universal (happen to most people) or probabilistic (only occur in some people)



Life expectancy around the world

1. Europe
Much of Europe enjoys a healthy life expectancy of more than 72 years.

2. North America
Canadians have a slightly higher life expectancy than Americans.

3. South America
The largest country has one of the lowest life expectancies.

4. Africa
Most of Africa, being undeveloped, has much lower life expectancy.

5. Asia
Asia has nearly every range of life expectancy within its borders.

6. Japan
Japan is the Asian country with the highest average life expectancy on the continent.

7. Indonesia
Indonesia is on a par with much of Asia.

8. Australia and New Zealand
These industrialised countries have an 80+ life expectancy.

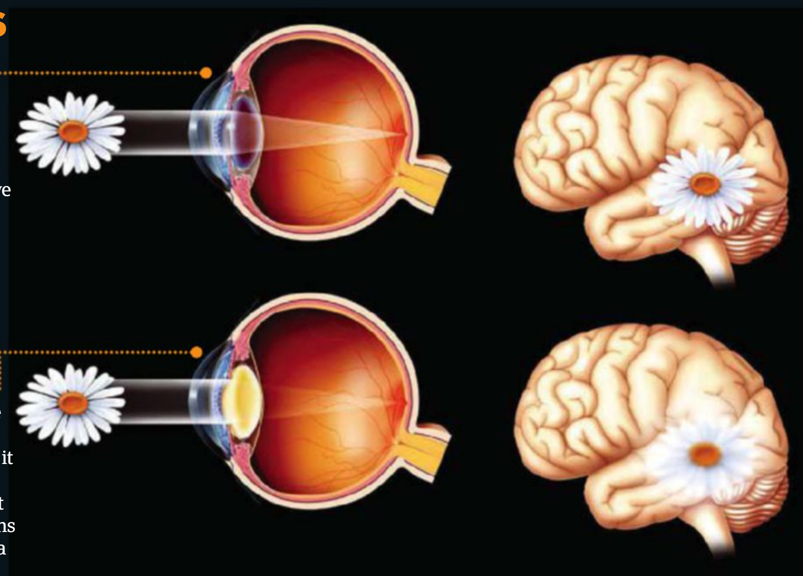
The senses

All of the senses decline as we age. Hearing declines because the structures in the ear break down over time. Damage to the auditory nerve, which relays the signal to the brain, may also be to blame. Vision also lessens because older eyes are less responsive, sharp or sensitive. The eye muscles can also become less responsive, resulting in a loss of peripheral vision and a narrower depth of field. Taste and smell both decrease with age as well. The 9,000 tastebuds with which we are born decrease over the course of our lives. Smell may diminish due to a loss of nerve endings in the nose. Decreased blood flow to the areas of the brain and nervous system that receive touch information may be responsible for a loss of sensations like pain, cold, heat and vibration. The brain itself gets smaller over time and chemical processes (as well as a lack of stimulation) result in age-related complaints such as memory loss.

Cataracts

1. Normal lens
In a person with a normal lens, light from an image passes through the lens and is projected onto the tissue at the back of the eye called the retina. The retina changes the image to a nerve signal and transmits it to the brain, where it is processed.

2. Lens with cataract
If protein clumps onto the lens (due to wear and tear or diseases like diabetes), it can create a cloudy area known as a cataract. Light is diffused through the lens to the retina, resulting in a blurry image.



© Science Photo Library

7. Old age
A more elderly appearance results from wrinkles, hair loss and decreased muscle tone.

© Science Photo Library

Slowing down the ageing process

Although ageing itself is inevitable (at least currently), there's a lot that we can do to slow down the ageing process. Visible signs of ageing like wrinkles can be diminished by avoiding Sun exposure and other risk factors like smoking. Internal signs of ageing can all be combated to some extent by lifestyle changes. Weight-bearing exercises such as weight-lifting, for example, have been shown to help maintain bone density and stave off osteoporosis. Aerobic exercise like walking or cycling can prevent weight gain – which leads to numerous diseases and conditions that age us – as well as improve cardiovascular health. Diet also plays a part in ageing – a balanced one can not only reduce the risk of diseases like type two diabetes but also keep our immune systems operating at their peak for longer. Some researchers treat ageing like a disease. To that end, stem-cell treatments and even cryogenics are looked to as a potential cure. But at what cost? Others feel that we weren't meant to live forever and should focus on ways to age comfortably.

© SPL

There are a number of ways to slow down the ageing process

Trampoline science

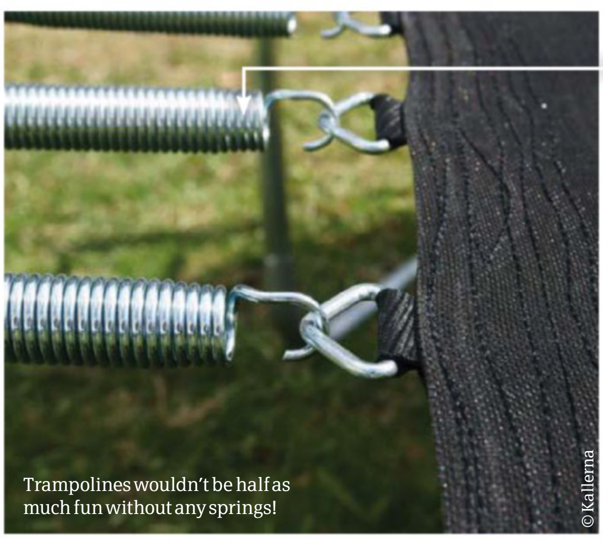
How do trampolines make us jump high in the air?

Trampolines provide a perfect example of both Newton's laws of motion and Hooke's law of elasticity. The three key elements are the jumper's weight, the springs and the fabric, which provide the trampolinist with all they need to get in the air.

The total energy of the system (namely, the person jumping on the trampoline) remains constant, so their kinetic and potential energy must increase and decrease relatively to ensure energy conservation. This transfer of energy is made possible thanks to Hooke's law, which relates to elasticity. A trampoline is basically an elastic disc connected to several springs. When a person lands on the trampoline they stretch both the springs and the fabric surface. Hooke's law states that stretched springs will always try to return to their original shape. Therefore, the springs, and so the surface, push against the person's weight, equal to the force they exert downwards, launching them upwards into the air.

All moving objects are said to have kinetic energy. While jumping on a trampoline a person's kinetic energy will change depending on their velocity. Maximum kinetic energy is achieved at the moment just after leaving the trampoline and just before returning to it, when velocity is at its greatest. The minimum occurs at the top of the jump and when at rest on the trampoline, just before the springs propel them up again.

The potential energy is determined by the jumper's mass as well as their height from the ground; the higher the trampolinist is from the ground, the greater the potential energy. This changes inversely to kinetic energy under the laws of the conservation of energy, where total energy is kinetic plus potential. In other words, as the individual leaves the trampoline and rises, their speed decreases and thus so does their kinetic energy, but in contrast their potential energy increases. As they reach the top of the jump and begin to fall, the opposite is true as potential gives way to kinetic, and the process repeats.


Trampolines wouldn't be half as much fun without any springs!

© Kallerna

DID YOU KNOW?

Wrinkle free

Babies are born covered in a waxy substance called vernix caseosa. This mainly consists of sebum and sloughed-off dead skin cells from the developing foetus. It's thought this coating helps stop the baby coming out wrinkly – as we would were we to spend nine months in the bath!

DID YOU KNOW? *Artificial sweeteners such as saccharin don't affect blood sugar, making them ideal for diabetics*

Why do we get spots?

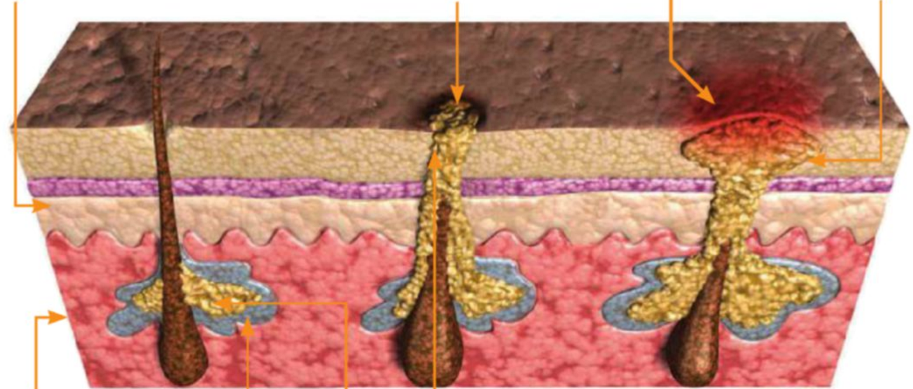
Find out what causes pimples to form on the surface of human skin

Pimples are caused by sensitivity to the testosterone hormone present in both males and females, which can trigger the overproduction of an oily substance called sebum. Sebum, which is produced by sebaceous glands attached to hair follicles in the dermis, helps keep hair and skin waterproof.

Your skin is constantly renewing itself, and while new cells are produced in the lower layers of skin, the old dead cells are sloughed away from the surface. This, together with excessive sebum production, can lead to acne and pimples.

Sebum normally travels through the hair follicle to the surface of the skin. However, if a pore becomes blocked by a few dead skin cells that haven't been shed properly, the sebum builds up inside the hair follicle. This oily buildup is a breeding ground for bacteria, which then accumulate and multiply around the area, making the skin inflamed and infected. This results in the pimple.

Whiteheads and blackheads are types of acne pimples known as comedones. Blackheads are open comedones, which means the blockage of sebum is exposed to the air, causing oxidation of the sebum (like when an apple browns). Whiteheads, on the other hand, are closed comedones and are not exposed to air as they're covered by a layer of skin.



Artificial flavourings

How can scientists synthetically replicate the taste of real food?

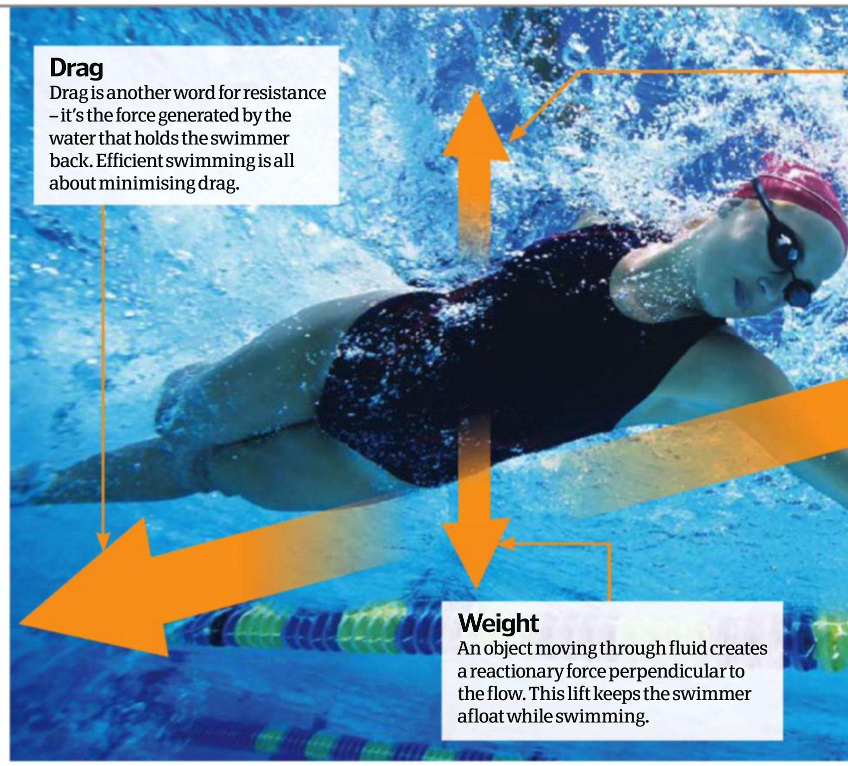
Artificial flavourings are used to improve the taste of food or to chemically re-create a flavour that cannot be achieved through conventional production. Artificial flavours can be produced cheaper than their natural counterparts and they can also be so concentrated that much less of them is required to generate the same taste, making them very cost-effective.

To chemically re-create the taste of a naturally occurring flavour, specialist flavour chefs first obtain the essential chemicals from the foodstuff they're trying to emulate. These chemicals are leeched out of the food through either boiling, roasting or some other refining process. This leaves a concentrate (the natural flavouring), which can be further vaporised or liquefied to obtain an even more concentrated version.

By looking at the substance through a chromatograph (an instrument that enables the separation of complex mixtures) flavour scientists can establish how the molecules in the concentrate are arranged, and then replicate the chemicals to create a man-made equivalent of the original flavour. Differing combinations of the same molecules can lead to a whole host of different flavours.

Olympic physics revealed

Discover physics in action as we explore the pure science at the heart of several of your favourite Olympic sports events

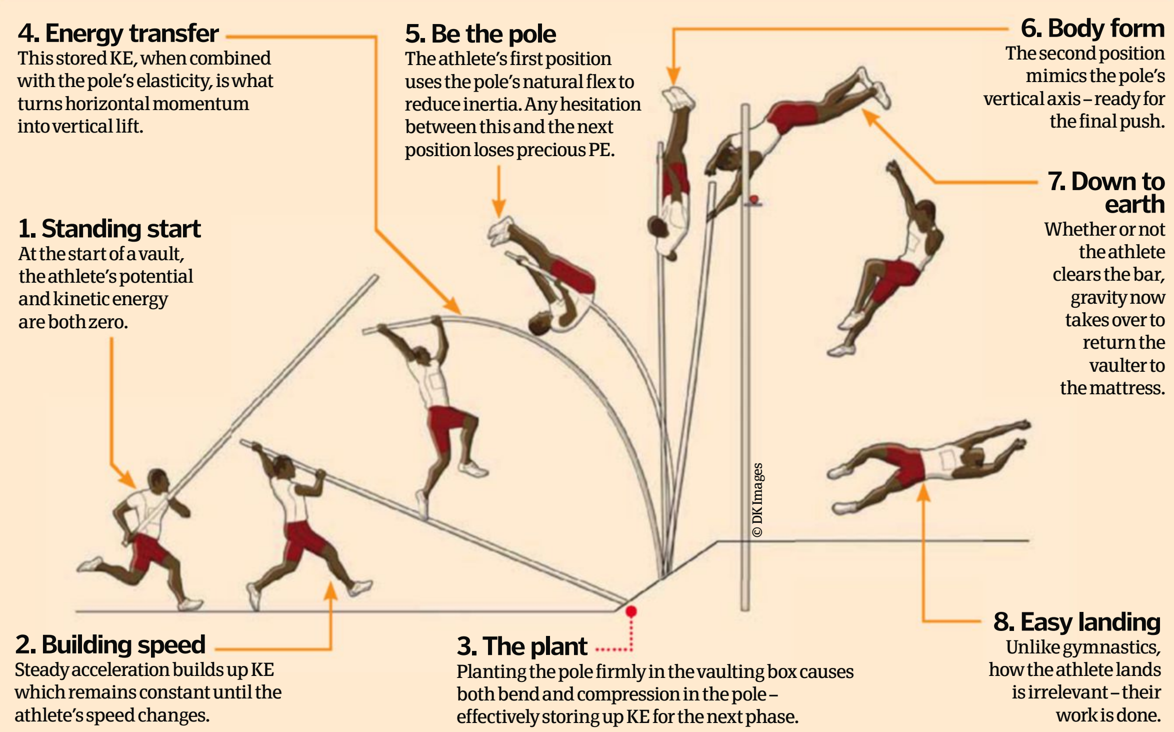


With the 2012 Olympics fresh in our minds, it's not just sport lovers who became excited, but physics fans too. Because whether it's how fast they run, how high they jump or how many records they break, it's the laws of physics that these athletes will really be testing.

In scientific terms all sports can be boiled down to physics – in particular the interaction of natural forces; indeed, any influence that causes an object to change speed, direction or shape. There are many forces at play in the sporting field, from gravity (so common and influential it is known as a 'fundamental' force) to others like friction and resistance, which are explained in Isaac Newton's three laws of motion.

Of course, the athletes are important too, negotiating these forces through a combination of instinct and muscle memory. Ultimately, it's up to you whether you admire Usain Bolt for being an amazing athlete or an unsung master of physics!

So how do these invisible forces contribute to the Olympic events we love to watch? We have taken a look at the pole vault, swimming, the hammer throw and gymnastics – four very different events all governed by the same fundamental rules.



The pole vault

Understanding the science behind sport is hard enough when it's just man versus physics; throw another object into the mix and things get even more complicated.

Pole vaulting, for instance, is based on the same principles as high jump: that is, converting linear momentum into vertical lift. What makes it different and harder to calculate is the pole, a carbon-fibre tube which is designed to first absorb and then increase kinetic energy (KE) as it bends and flexes. Meanwhile, the athlete still needs perfect timing to ensure the run-up, the plant and the final push over the bar conserve as much potential energy (PE) as possible through these key transitions.

It's a feat that seems more incredible the more you appreciate how many elements have to go just right to achieve the perfect vault – one reason why Sergei Bubka's world record of 6.14 metres (20.14 feet) has stood since 1994.

RECORD BREAKERS
100 METRES

0.8sec

USAIN BOLT

Between 2007 and 2009, Usain Bolt lowered the 100 metres world record by an average 0.8 seconds per year. If that level of progress continued, running the 100 metres would take literally no time at all in under 200 years.

DID YOU KNOW? *Steve Redgrave CBE is the only Olympian to win gold at five Games in a row: 1984, 1988, 1992, 1996 and 2000*

Swimming

When you watch someone swimming, it's easy to think they are dragging themselves through the water. However, on the contrary, they are being pushed.

Newton's third law states that to every action force there is an equal, but opposite, reaction force, meaning that as the swimmer kicks with their legs or pulls with their arms, force is applied downwards and backwards, prompting a reactive force from the water pushing the body up and forwards.

Hardly surprising then that the swimmer's top priority is to reduce drag by any means possible – from perfecting dives to developing new suit materials and designs that minimise surface area when in the water.

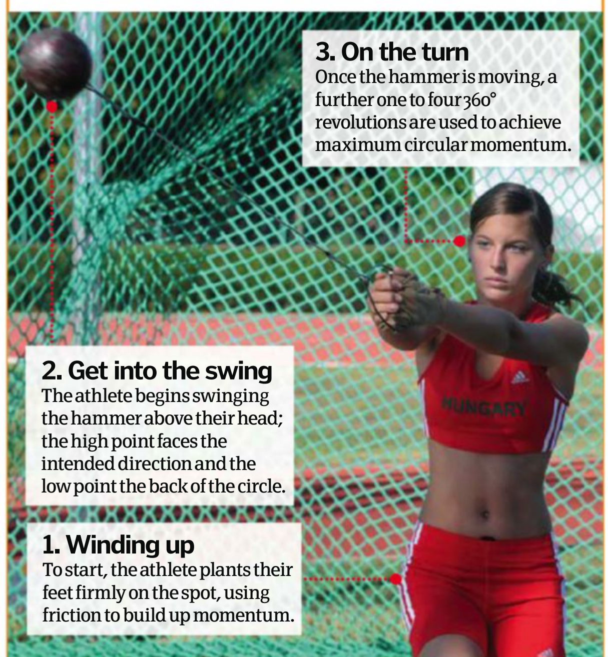
But that's not all. The faster an object travels through any element, the greater the resistance it encounters. As water is 773 times as dense, and 100 times more resistant, than air, top swimmers need to work harder than, say, top sprinters. Conversely, because of buoyancy, they are less likely to get injured.

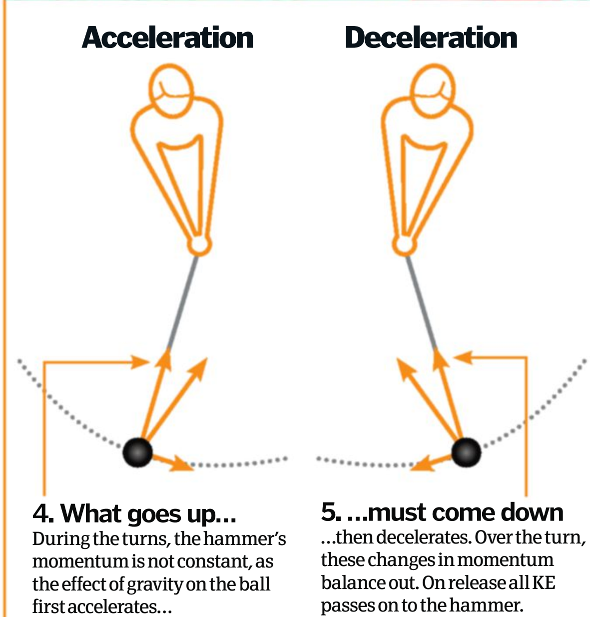
The hammer throw

The hammer consists of three separate and independently moving parts: the handle, 1.2-metre (3.9-foot) chain and, for men, 7.3-kilogram (16-pound) ball; the women's hammer weighs almost half that at four kilograms (8.8 pounds). Each part reacts to the same forces in slightly different ways.

The perfect throw is split into three key phases. The first is the winds, where the athlete swings the hammer around their head to build up circular momentum. The second is the turns, one to four rotations that maximise the hammer's PE. And finally the release, which is about judging the right time, angle and height to achieve maximum velocity as a measure of the hammer's kinetic energy.

Additionally, like all throwing and shooting events, wind resistance can play its part. A strong headwind is capable of reducing a throw's potential length by several centimetres.





Somersault

Though rarely seen on its own, the somersault lies at the heart of many Olympic gymnastics disciplines. Somersaults are all about maintaining angular momentum (inertia times velocity) while the body is in the air. During the tumble itself, the arms and legs are tucked closely into the body, helping to reduce inertia as it rotates through 360 degrees in either direction. The more height and velocity achieved through each tumble, the more rotations can be completed before gravity has time to pull the athlete back down.

This explains why a single forward or back somersault can be made from a standing start but multiple tumbles, twists and pikes always require a run-up. This increases linear velocity and changes the angle of projection – allowing for several longer, faster and higher tumbles.

Electromagnetism

How electricity and magnetism combine to produce one of the most crucial forces on the planet

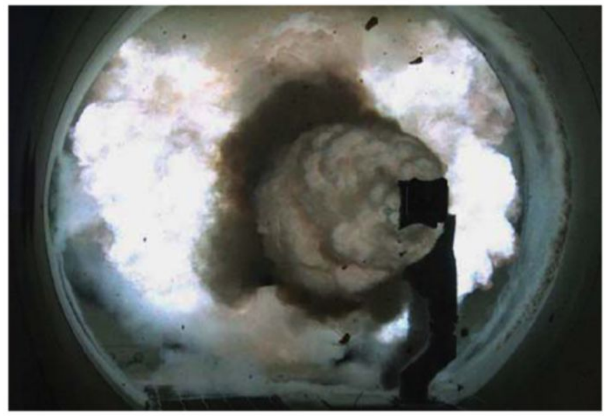
Prior to the 19th century electricity and magnetism were considered separate forces. However in 1873 Scottish physicist James Clerk Maxwell showed that despite the two behaving quite differently alone – electric forces rely on electric charges in motion or at rest, while magnetic forces are produced by and act on only moving charges – together they work in unison as an electromagnetic force.

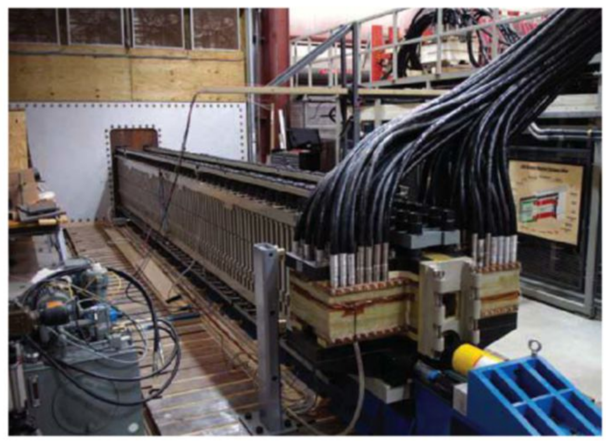
Electromagnetism is one of the four fundamental forces of nature – the other three being gravity, the weak force (radioactive decay) and the strong force (which binds protons and neutrons together to form the nucleus of an atom). Of the four, the electromagnetic force is responsible for the majority of physical and chemical properties of atoms and molecules, which are pervasive in everyday life. These include those exhibited when a human pushes or pulls any physical object, such as a chair or shopping trolley, or when they use an electrical appliance. For example, radios receive their audio information via electromagnetic waves carried through space, while photocopiers attract particles of ink to paper via electric force.

Electric and magnetic forces are detected in regions known as electric and magnetic fields. These travel together through space as electromagnetic radiation, with the fields sustaining each other. Examples of electromagnetic waves include visible light, X-rays and radio waves. In addition, all electromagnetic waves travel at the speed of light – this is how your television is able to receive images live – while force is transferred by carrier particles known as photons.

Crucially, both electric and magnetic fields can produce each other merely by changing charge and position. This principle is today used in electric motors worldwide, as well as electrical generators (where a rotating magnetic field produces an electric current).


© Les Chatfield

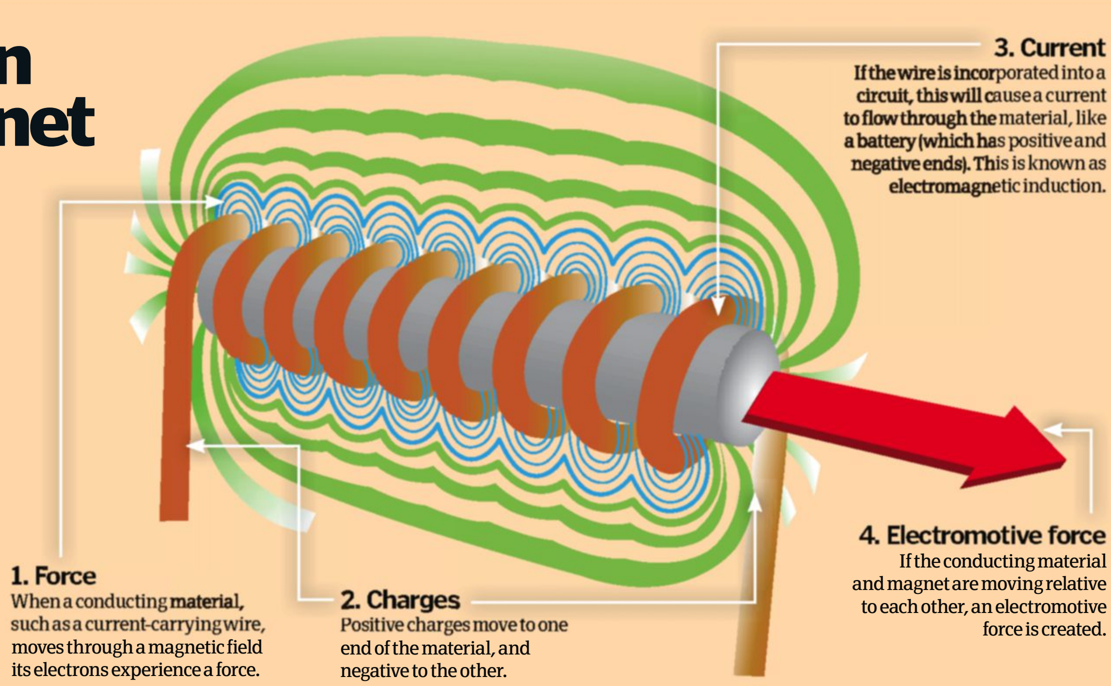

The US Navy used electromagnetism to create a high-powered electromagnetic railgun (EMRG)



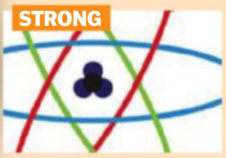
How does an electromagnet work?

When a conducting material, such as a current-carrying wire, moves through a magnetic field its electrons experience a force. Positive charges move to one end of the material, and negative to the other. If it is connected in a circuit, this will cause a current to flow through the material, like a battery (which has a positive and a negative end). This is called electromagnetic induction.

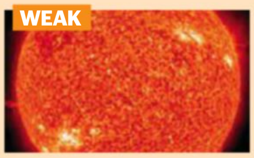
If the conducting material and magnet are moving relative to each other – such as one rotating around the other – then an electromotive force is produced. An electromotive force is what generates electric power in a power station, for example.



Head to Head
THE OTHER FORCES



1. Strong force
The strong force is the strongest of the four fundamental forces but has the shortest range. It holds the nuclei of atoms together.



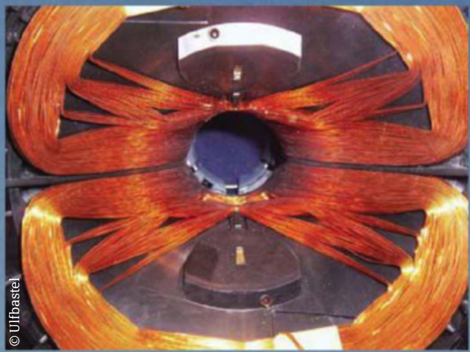
2. Weak force
The weak force interacts with quarks within atoms, and is crucial to the structure of the universe. One place where it's key is atom decay in the Sun.

3. Gravity
While gravity is the weakest of the fundamental forces it acts over the greatest range, as demonstrated by the cosmic interactions throughout the universe.

DID YOU KNOW? Magnetic levitation trains use strong electromagnets to carry trains upon a 'cushion' of magnetic repulsion

How a scrapyard electromagnet works

2. Iron disc
An iron disc at the end of the crane becomes a temporary magnet once its electromagnet is activated by the operator.



© Ulfbastel

The copper coils at the heart of a electromagnet. The more coils the stronger the force produced

3. Magnetised
The magnetised disc is hovered over the junk and draws out any metal scrap. It can lift objects as heavy as a car, but will drop its load as soon as the current is cut.

1. Scrap pile
At a scrapheap, all kinds of waste often arrive jumbled together and need to be sorted for processing. Metal can be located using electromagnetism.

Powerful electromagnets are used in scrapheaps to separate metal objects from the waste

© Science Photo Library

© Ashley Poland

Sword swallowing

How do performers put long objects safely down their throats?

Sword swallowing is an extremely dangerous performing art that requires the participant to have complete control over many of their body's voluntary and involuntary reactions, including the gag reflex. While many believe that this art is nothing more than a clever trick or an illusion, the reality is that this pastime is potentially fatal.

Learning to swallow a sword takes many years of careful practice. The act of actually swallowing a sword directly involves a human's upper gastrointestinal (GI) tract. This series of organs includes the throat, the oesophagus and the stomach, and is where the sword moves through. This tract is slightly curved, while swords used in this performing art are generally straight, which has to be taken into consideration.

Inside the GI tract are two types of muscle tissue – skeletal and smooth – in addition to a lubricating layer called the mucosa. Skeletal muscles, which govern things such as talking and typing, are controlled voluntarily, but smooth muscles are involuntary and they control bodily functions like moving food during digestion. A sword swallower must retain complete control over all of these muscles to ensure their safety.

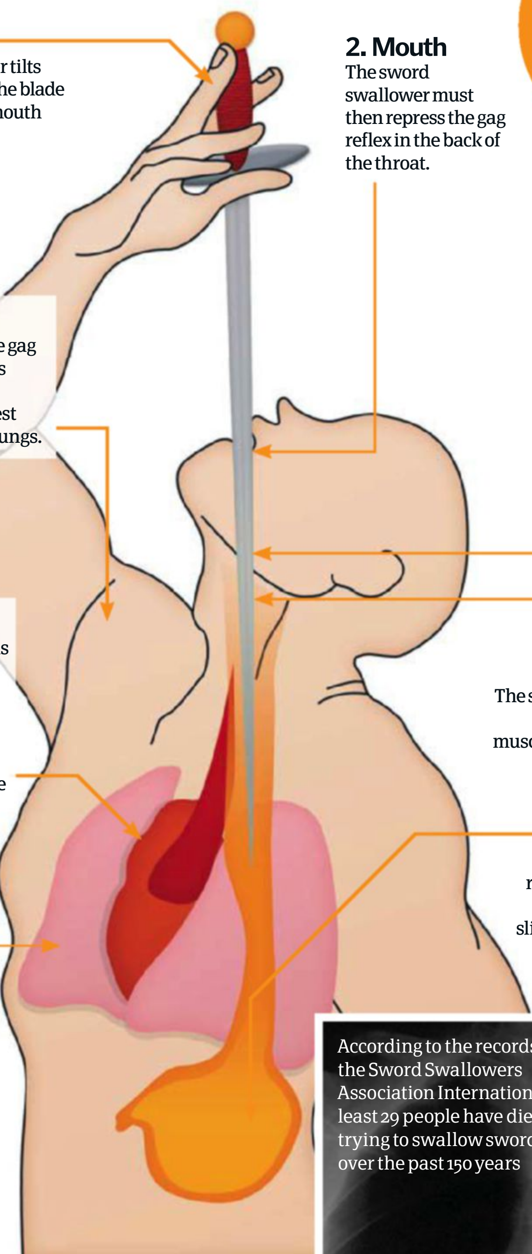
Dan Meyer was the first in his profession to swallow a sword while underwater

© Tim O'Brien, Ripley Entertainment

Sword swallowing with a pro

Ten times world champion sword swallower Dan Meyer, president of Sword Swallowers Association International (www.swordswallow.org) and recipient of countless awards relating to his act including five world records and the 2007 Ig Nobel Prize in Medicine, talks us through the step-by-step process of ingesting a blade.

Disclaimer
Sword swallowing is a dangerous and potentially fatal performing art that requires years of practice and close supervision. Under no circumstances should you attempt to re-create the feats on display here.



1. Insertion
The sword swallower tilts the head back, and the blade is inserted into the mouth over the tongue.

2. Mouth
The sword swallower must then repress the gag reflex in the back of the throat.

3. Oesophagus
The sword swallower opens the epiglottis and finds the proper alignment into the upper oesophagus.

4. Throat
The sword swallower represses the peristalsis reflex, the muscles that cause the throat to contract and swallow.

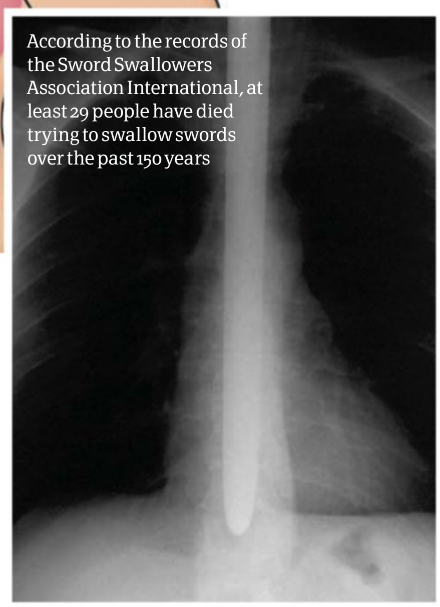
5. Chest
While repressing the gag reflex and peristalsis reflex, the blade is inserted into the chest cavity between the lungs.

6. Heart
Since the oesophagus leans on and wraps slightly around the heart, the sword blade nudges or displaces the heart a little in order to make a straight path.

7. Ribcage
The blade is inserted past the ribcage, past the sternum, and through the diaphragm to the lower oesophagus. The sword swallower then relaxes the lower oesophageal sphincter which seals off the stomach.

8. Stomach
The sword swallower represses the retch reflex in the stomach, and finally slides the blade past the liver and kidneys down to the bottom of the stomach.

© Ashley Poland



According to the records of the Sword Swallowers Association International, at least 29 people have died trying to swallow swords over the past 150 years

Don't stop brushing
1 The physical brushing of your teeth does most of the work; toothpaste just makes it more effective. It's better to have a toothbrush with no toothpaste than the other way round!

Substitute
2 Baking soda with salt can be an effective toothpaste substitute. Baking soda increases pH, which fights off enamel-damaging bacteria, while salt works as an abrasive.

The orange juice effect
3 No one knows exactly why OJ tastes so bad after brushing, but some attribute it to sodium lauryl sulphate, which inhibits our sweet tastebuds and sensitises our bitter ones.

Leaded toothpaste
4 The first collapsible toothpaste tubes were made of lead until the Fifties, when people realised that high doses of lead are harmful. Lead toothpaste tubes were recycled during WWII to make bullets.

Pea-sized is best
5 Due to the foaming action of toothpaste, a pea-sized amount is all you need for effective brushing – using more than this is just a waste.

DID YOU KNOW? Ancient Egyptians crushed rock salt, mint, dried iris flowers and pepper to form an early type of toothpaste

Toothpaste actually contains detergent but the soapiness is masked by strong flavourings like mint

How toothpaste works

Find out what's inside toothpaste and how it helps to keep your pearly-whites clean

Toothpastes contain a mixture of abrasives, detergents and foaming agents. When combined with regular brushing, toothpaste helps fight against tooth decay, promoting good oral hygiene.

Some bacteria in the mouth attach onto the surface of our teeth – the enamel layer, forming a biofilm called plaque. Abrasives in toothpaste – common examples being calcium carbonate and hydrated silica – help to remove plaque by adding a gritty texture to the paste.

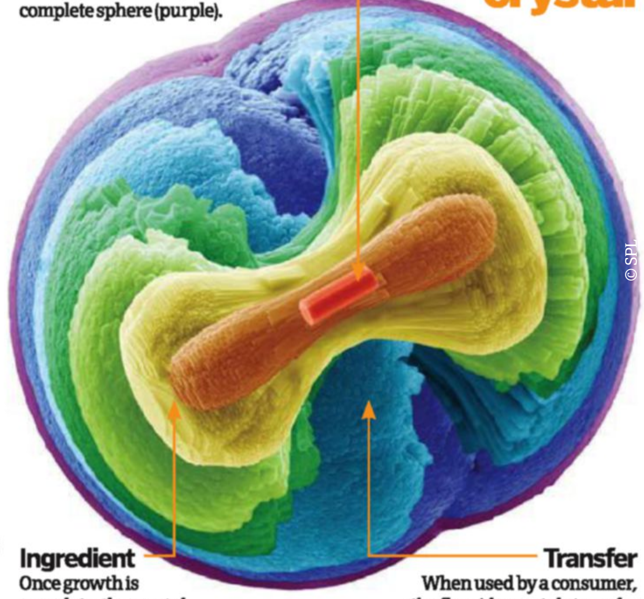
Sodium lauryl sulphate is another common ingredient that is found in toothpaste and this is responsible for the substance foaming up during brushing. This allows for a more even spread of toothpaste throughout the mouth.

Perhaps the most active ingredient in toothpaste, though, is fluoride – often in the form of sodium fluoride – as it is known to strengthen tooth enamel. Fluoride also reduces the amount of acid that bacteria on your teeth can produce.

Non-active ingredients such as water, binding agents and preservatives, respectively, give toothpaste its consistency, help the other ingredients mix and mean you don't have to keep it in the fridge.

Although toothpaste comes in a variety of flavours, the most common are menthol based, such as peppermint or spearmint. Menthol interacts chemically with the nerve sensors that detect cold temperature, making them more sensitive to cold. This creates the illusion that your mouth is cooler than it actually is, leaving behind a feeling of freshness. Mint is also used because it is a strong yet relatively impartial taste that disguises the fact you are washing your mouth out with soap.

Lab-grown fluoride crystal



"Perhaps the most active ingredient in toothpaste is fluoride – often in the form of sodium fluoride"

Earn your stripes

Stripes are added to toothpaste for aesthetic value. Before the bottom end of a toothpaste tube is sealed during manufacture, different coloured stripes are added by a pump as a bigger version of what comes out the nozzle when you squeeze. For red, white and blue striped toothpaste, the white paste goes in the middle of the tube, with the red and blue pastes on either side. To ensure the stripes don't mix in the tube, some manufacturers may add a tube inside to separate them. In the case of squeezy tubes that have no inner tube, the stripes have varying viscosities which stops them from mixing.

Whitening explained

Stains inevitably make their way onto our teeth from the things we eat and drink – tea, coffee and wine being some of the worst culprits. Teeth also get darker with age due to changes in their mineral content.

Whitening toothpastes contain harsher abrasives than ordinary toothpastes, making them more effective at removing stains from the enamel. However caution should be used as aggressive brushing with these toothpastes can damage the enamel.
Some whitening products contain hydrogen peroxide which effectively bleaches the teeth – these types of toothpaste should also be used with care as hydrogen peroxide can cause a number of unwanted side effects like nausea.

DNA

If the human body is an infinitely complex machine then DNA is our ingenious programming code

Imagine a masterwork of literature – perhaps Tolstoy's *War And Peace* or Shakespeare's collected plays – entirely written in a four-letter language. Impossible, right? How could you express such complexity of thought and emotion with only four letters? Now think of life on Earth in all its magnificent diversity, from the humblest slime mould to the Olympic athlete. The variety, richness and beauty of life is far greater than any manmade work of art or science, but with our evolving understanding of DNA, we now know that all of it – every last cell – is written with four simple letters: A, T, C and G.

In very basic terms, DNA – which is short for deoxyribonucleic acid – is a molecule that carries genetic information. In human anatomy, we call the sum of this information the human genome. Each of the 100 trillion cells that makes up your body contains DNA – except for red blood cells, which do not have a nucleus. And, remarkably, each of these copies of DNA contains not only the instructions for operating that particular liver cell or brain cell, but also for creating and operating every other cell in the body.

The DNA molecule isn't a circular clump of atoms, but rather a super-long, super-thin strand of atoms tightly coiled into cylindrical packages called chromosomes. No microscope is powerful enough to view the structure of DNA, but thanks to pioneering researchers like James Watson and Francis Crick (and the uncredited Rosalind Franklin), we know that it mostly

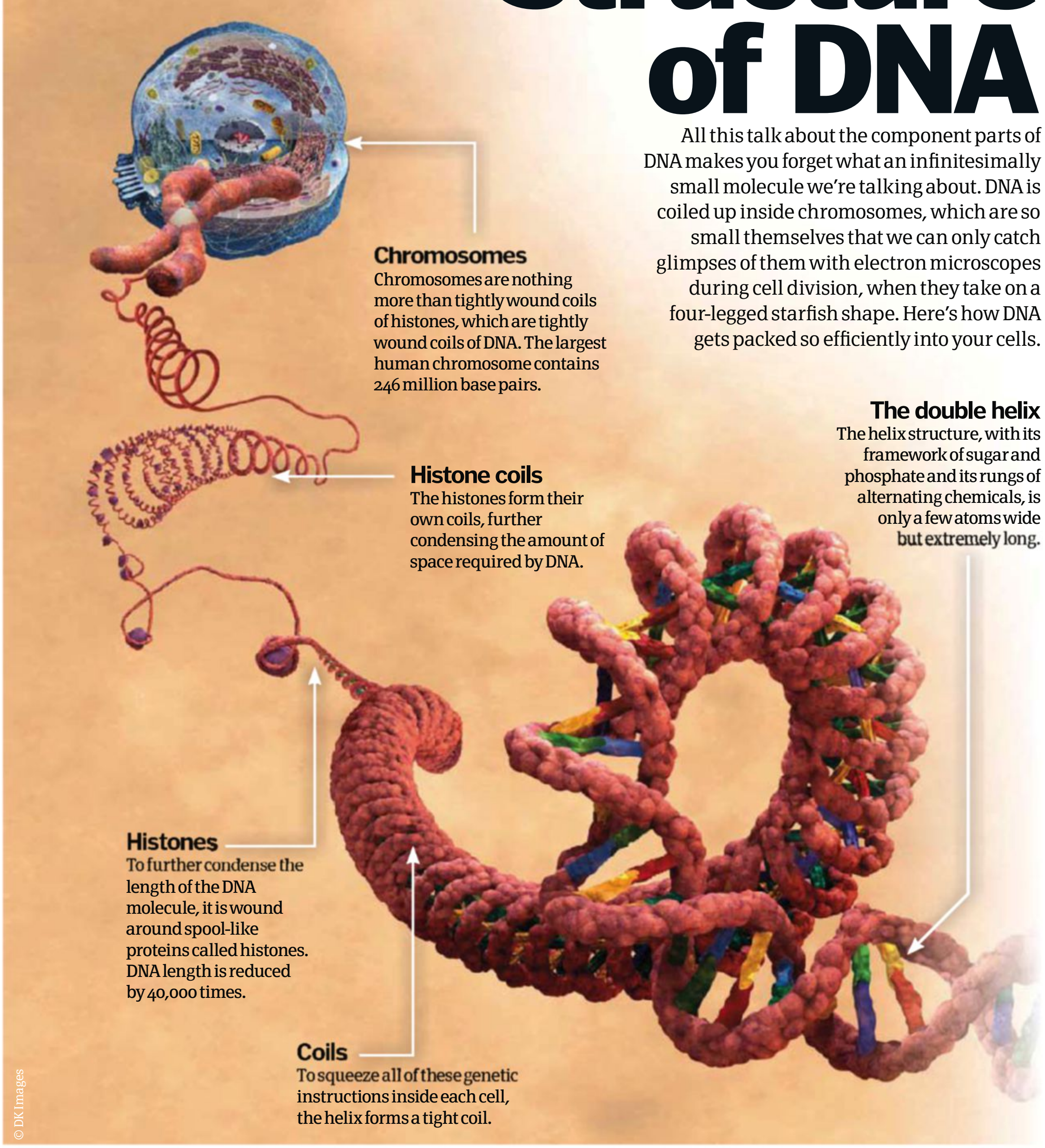
THE STATS
GEN UP ON GENOMES

NUCLEOTIDES	3.2bn
NUMBER OF GENES	25-30k
NUMBER OF GENES IN MOUSE GENOME	25-30k
GENES WITH KNOWN FUNCTION	50%
YEARS TO CALCULATE HUMAN GENOME	10
PROTEIN-ENCODING DNA	2%

DID YOU KNOW? *There's a copy of our DNA in every cell in the body, with the exception of red blood cells*

Structure of DNA

All this talk about the component parts of DNA makes you forget what an infinitesimally small molecule we're talking about. DNA is coiled up inside chromosomes, which are so small themselves that we can only catch glimpses of them with electron microscopes during cell division, when they take on a four-legged starfish shape. Here's how DNA gets packed so efficiently into your cells.



exists as a double helix – two strands running in opposite directions linked together by weak hydrogen bonds.

Using complex biochemistry and powerful computers, researchers have been able to sequence every line of code written in human DNA. There are only four letters in this code, each standing for the four different types of nitrogen-based chemicals embedded into the DNA molecule. The plain text of the code looks like indecipherable gibberish, a total of 3.2 billion letters that read 'AATTTGGCCGTTAAGCTAACG…' unto infinity. But with careful comparisons between the genetic code of healthy individuals and those with medical conditions, we have been able to isolate those sequences of letters that code for obesity, blindness, heart disease and more.

We call these identifiable sections of code genes. Only a small fraction of these genes produce proteins – the molecules chiefly responsible for every function of the human body. Protein-creation is its own miraculous process. An enzyme called RNA polymerase copies a sequence of DNA code corresponding to a specific gene and creates a single-strand version called messenger RNA (mRNA). The mRNA travels out of the nucleus and into the cytoplasm, where it feeds its code into a ribosome, which churns out the necessary protein.

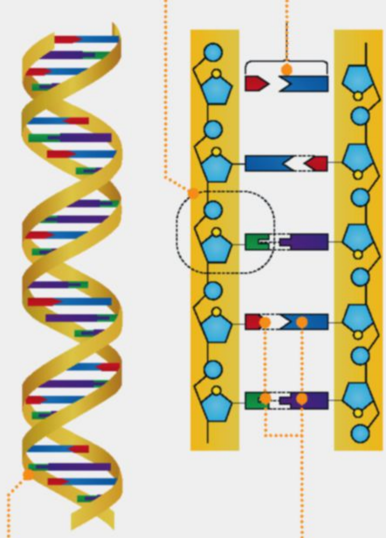
DNA is the fundamental fuel of evolution. Every time that DNA replicates itself (see DNA replication boxout over the page) there is a chance that a single A might become a T or a C. These coding errors, called mutations, don't always result in a major physical change. But over millennia, those mutations and traits that give their owners an advantage will be passed on with greater frequency than the less beneficial mutations. With enough time and an infinite number of errors, even a slime mould can become an Olympic athlete.

Base pairs

One of the most remarkable things about DNA is that this sub-microscopic blueprint of life is coded with only four elements called nitrogenous bases. The names of the four nitrogenous bases are adenine (A), thymine (T), guanine (G) and cytosine (C). Each nitrogen base is attached to a sugar molecule (deoxyribose) and a phosphate group. Together, this combo of nitrogenous base, sugar and phosphate forms a nucleotide. On a single strand of DNA, sequences of nitrogenous pairs (eg AAGTCTTCTG) are what encode genes for various traits like blue eyes or susceptibility to asthma. But DNA is more than a single strand. It's actually two strands of code running in opposite directions and bonded together in a unique shape called a double helix. The 'rungs' of the double helix ladder are formed by weak hydrogen bonds; A always pairs with T and C always pairs with G. See the section on DNA replication to understand why these predictable pairings are so important.

Nucleotide
The building blocks of DNA are nucleotides, combinations of a sugar, a phosphate group and a nitrogenous base.

Hydrogen bonds
When two DNA strands line up in opposite directions, the nitrogenous bases form weak hydrogen bonds: A with T and C with G.



Double helix
These bonded pairs of nitrogenous bases make up the 'rungs' of the double helix ladder while the sugar and phosphate constitute the 'backbone' of the DNA structure.

Nitrogenous bases
There are only four kinds of nitrogenous base. Incredibly, the endless variety of life is programmed by combinations of just these four elements.

Genomes and chromosomes

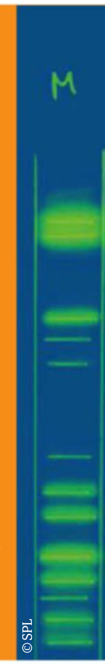
Everyone is made up of an equal number of chromosomes from their parents, which combine to create a unique new blueprint

Your DNA blueprint (genome) doesn't exist as one continuous scroll rolled tightly into the nucleus of each cell. Instead, your DNA is divided into 46 'chapters' called chromosomes – 23 from each of your parents. Each chromosome is essentially a tightly coiled strand of DNA. The 23 chromosomes donated from your mum and the 23 donated from your dad pair up to form the 23 chromosome pairs found in each of your cells. Some chromosomes contain lots of genetic material, while others carry comparatively little. Chromosome 1, for example, is the biggest, carrying eight per cent of your total DNA. Researchers have identified the sections of genetic code on each chromosome that produce proteins responsible for various traits and disorders. Those sections of useful code are called genes.

Genetic profiling

How do forensic scientists look at variations in DNA to prove suspects innocent or guilty?

Only two per cent of the human genome encodes for the synthesis of proteins, but that doesn't mean the other 98 per cent is junk. Among the reams of non-encoding genetic material are repeating sequences that vary between individuals. While mapping the genome, scientists discovered specific points on each chromosome (loci) where these repeating sequences reside. Using chemical processes, criminal investigators can measure the length of these sequences in a blood or tissue sample and compare them with samples taken from suspects or in DNA databases. The measurements are taken at 13 loci spread across the 23 human chromosomes, so chances of a false match are extremely improbable. The same method of genetic profiling has been used to exonerate hundreds of falsely convicted criminals, some of them serving time on Death Row in the USA.



© SPL

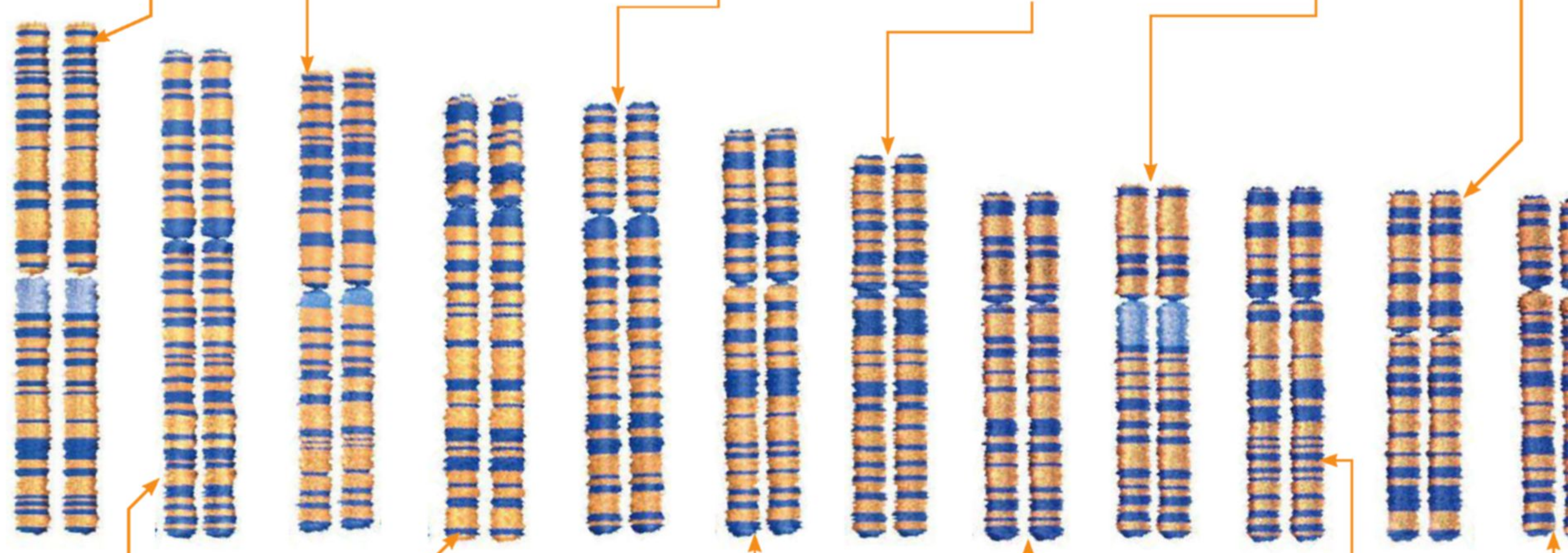
1 (Chromosome number)
Number of genes: 3,511
Number of base pairs: 246 million
Associations and conditions:
Breast cancer, prostate cancer, brain cancer, colon cancer, cataracts, glaucoma, macular degeneration, muscular dystrophy, leukaemia, basal cell carcinoma, deafness and osteoporosis.

3
Number of genes: 1,926
Number of base pairs: 199 million
Associations and conditions:
Severe obesity, colon cancer, small-cell lung cancer, pancreatic cancer, familial dementia, sucrose intolerance, insulin-resistant diabetes mellitus, dopamine receptor and shortness of stature.

5
Number of genes: 1,633
Number of base pairs: 181 million
Associations and conditions:
Dwarfism, serotonin receptors, taste receptor, bronchial asthma, susceptibility to nocturnal asthma, deafness, susceptibility to attention deficit hyperactivity disorder, colorectal cancer and x-ray repair.

7
Number of genes: 1,882
Number of base pairs: 158 million
Associations and conditions:
Lunatic fringe, polydactyly (extra fingers or toes), susceptibility to autism, cystic fibrosis, susceptibility to colitis, tumour suppression, susceptibility to coronary artery disease, speech-language disorder and myopathy (muscle disease).

9
Number of genes: 1,534
Number of base pairs: 136 million
Associations and conditions:
Sex-reversal, ovarian cancer, leukaemia, melanoma, bladder cancer, pituitary hormone deficiency, susceptibility to lead poisoning, cardiomyopathy, rufous albinism and pseudohermaphroditism.



2
Number of genes: 2,368
Number of base pairs: 243 million
Associations and conditions:
Colorectal cancer, ovarian cancer, dyslexia, obesity, epilepsy, cleft palate, repair of ultraviolet damage, febrile convulsions, hypothyroidism and Parkinson's disease type.

4
Number of genes: 1,444
Number of base pairs: 191 million
Associations and conditions:
Red hair colour, hepatitis B virus integration site, phenylketonuria, severe combined immunodeficiency, acute myeloid leukaemia, juvenile periodontitis and a susceptibility to alcoholism.

6
Number of genes: 2,057
Number of base pairs: 170 million
Associations and conditions:
Dyslexia, psoriasis susceptibility, schizophrenia susceptibility, maple syrup urine disease, coeliac disease (gluten sensitivity), inflammatory bowel disease, breast cancer, leukaemia and HIV susceptibility.

8
Number of genes: 1,315
Number of base pairs: 146 million
Associations and conditions:
Scurvy, colorectal cancer, spastic paraplegia, epilepsy, papillomavirus integration site, prostate cancer tumour suppressor, haemolytic anaemia, opiate receptor, non-Hodgkin lymphoma and renal cell carcinoma.

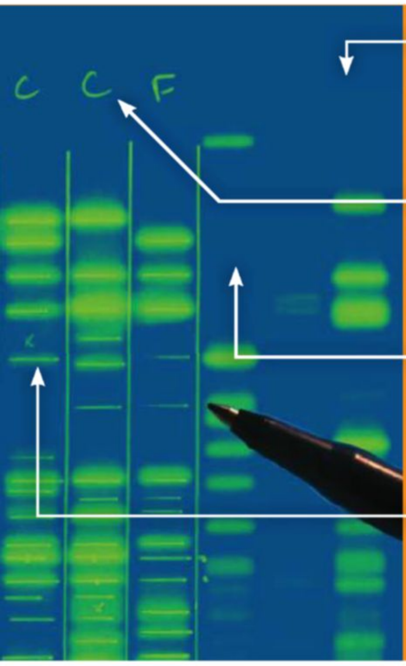
10
Number of genes: 1,391
Number of base pairs: 135 million
Associations and conditions:
Suppression of prostate tumours, chronic infections, leukaemia, malignant brain tumours, glaucoma, cataracts, neurofibrosarcoma, Graves' disease auto-antigen, Moebius syndrome and split hand/foot malformation.

DID YOU KNOW?

DNA unravelled

If you uncoiled the DNA from a single cell in your body, the molecule would measure two metres (6.5 feet) long and trillionths of a metre thin. Multiply that by the 100 trillion cells in your body and your DNA would stretch to the Sun and back more than 600 times!

DID YOU KNOW? *Changes in the DNA sequence are known as mutations and can be caused by UV irradiation, drugs and more*



Autorad
This image is an autorad (from autoradiography). Creation of the autorad is the final stage in the process of DNA profiling.

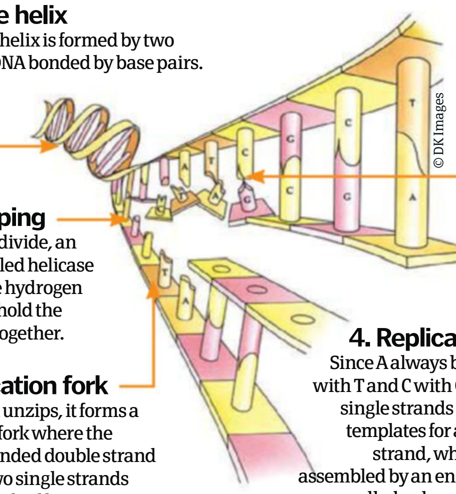
Samples
Comparing evidence from a crime scene and suspect samples, each DNA sample gets a column on the autorad.

Alleles
Each line represents an allele. Alleles are gene variations found at certain positions, or sites, on the chromosome.

Comparison
Alleles are measured at 13 sites, where scientists look for visual matches. The likelihood of a false match is 1 in 5 million.

DNA replication

The double helix consists of two strands of DNA running in opposite directions. The two strands are held together by hydrogen-bonded base pairs. When a cell prepares to divide, an enzyme called helicase 'unzips' the strands, breaking the weak hydrogen bonds. Half unzipped, the DNA takes on a fork shape, with each prong of the fork being a single string of unmatched nitrogenous bases. As A always bonds with T and C with G, that loose string of single bases serves as a template for creating its matching partner. Another enzyme called DNA polymerase finds the matching bases and bonds them with the originals. In this way, a single double helix can unzip and replicate to form two copies of itself.



1. Double helix
The double helix is formed by two strands of DNA bonded by base pairs.

2. Unzipping
For a cell to divide, an enzyme called helicase 'unzips' the hydrogen bonds that hold the base pairs together.

3. Replication fork
As the helix unzips, it forms a replication fork where the formerly bonded double strand becomes two single strands with unmatched base pairs.

4. Replication
Since A always bonds with T and C with G, the single strands act as templates for a new strand, which is assembled by an enzyme called polymerase.

11
Number of genes: 2,168
Number of base pairs: 134 million
Associations and conditions: Sickle cell anaemia, bladder cancer, osteoporosis, lung cancer, breast cancer, T-cell immune regulator, tumour susceptibility gene, Epstein-Barr virus modification site, Ewing's sarcoma and high bone mass.

14
Number of genes: 1,532
Number of base pairs: 105 million
Associations and conditions: Defender against cell death, deafness, immunodeficiency, Alzheimer's disease, basal ganglia calcification, Graves' disease, goitre, DNA mismatch repair gene MLH3 and congenital hypothyroidism.

18
Number of genes: 557
Number of base pairs: 76 million
Associations and conditions: Susceptibility to Parkinson's disease, schizophrenia, familial carpal tunnel syndrome, pancreatic cancer, colorectal cancer, autosomal dominant obesity and hepatitis B integration site.

22
Number of genes: 855
Number of base pairs: 49 million
Associations and conditions: Cat eye syndrome, colorectal cancer, succinylpurinemic autism, leukaemia inhibitory factor, glucose malabsorption and Yemenite deaf-blind hypopigmentation syndrome.

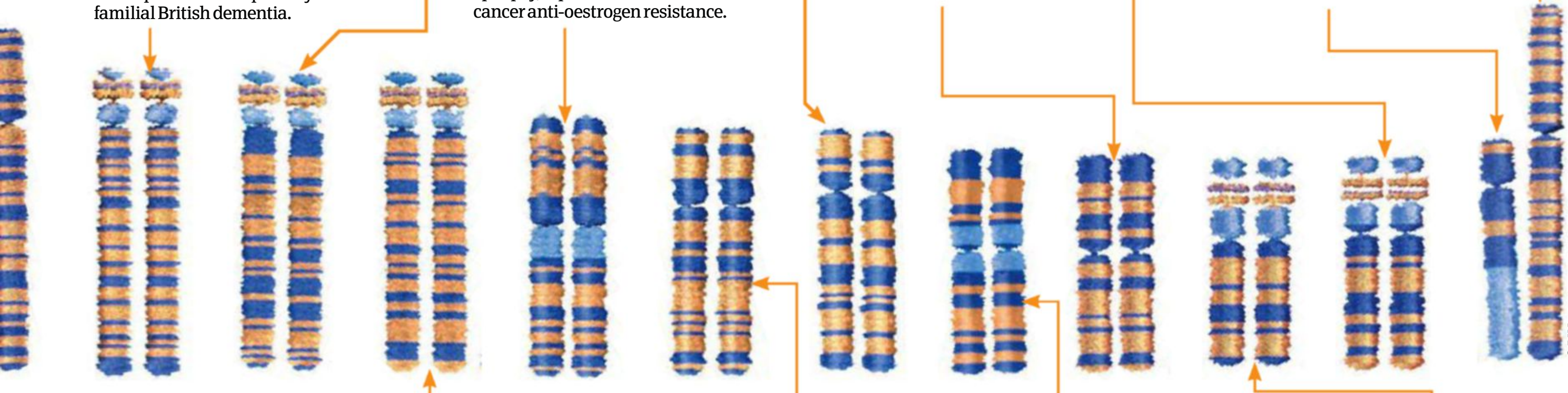
Y
Number of genes: 429
Number of base pairs: 50 million
Associations and conditions: Short stature, sex-determining region Y, gonadal dysgenesis XY type, male infertility due to spermatogenic failure and growth control.

13
Number of genes: 720
Number of base pairs: 133 million
Associations and conditions: Cholesterol-lowering factor, stem-cell leukaemia/lymphoma syndrome, early onset breast cancer, pancreatic cancer, x-ray sensitivity, schizophrenia susceptibility and familial British dementia.

16
Number of genes: 1,326
Number of base pairs: 90 million
Associations and conditions: Antidepressant-sensitivity, fish-eye disease, vulnerability to UV-induced skin damage, familial gastric cancer, corneal macular dystrophy, infantile epilepsy, alpha thalassemia and breast cancer anti-oestrogen resistance.

20
Number of genes: 891
Number of base pairs: 63 million
Associations and conditions: Fatal familial insomnia, gigantism, inhibitor of DNA binding, Creutzfeldt-Jakob disease, breast cancer and myeloid tumour suppressor.

X
Number of genes: 1,672
Number of base pairs: 153 million
Associations and conditions: Social cognitive function, night blindness, haemophilia A and B, green cone pigment colour blindness, mental retardation with psychosis and male breast cancer.



12
Number of genes: 1,714
Number of base pairs: 132 million
Associations and conditions: Lupus erythematosus, taste receptors, oral cancer, spinal muscular atrophy, acute alcohol intolerance, susceptibility to Alzheimer's disease, vitamin D-resistant rickets and nocturnal enuresis (bedwetting).

15
Number of genes: 1,249
Number of base pairs: 100 million
Associations and conditions: Susceptibility to hypertension, brown eye colour, brown hair colour, limb deformity, human coronavirus sensitivity, Tay-Sachs disease, severe mental retardation, dyslexia and albinism.

17
Number of genes: 1,773
Number of base pairs: 81 million
Associations and conditions: Delayed progression of HIV-1 disease, invasive pituitary tumour, susceptibility to Alzheimer's disease, susceptibility to myocardial infarction (heart attack), Duchenne-like muscular dystrophy, frontotemporal dementia and growth hormone deficiency.

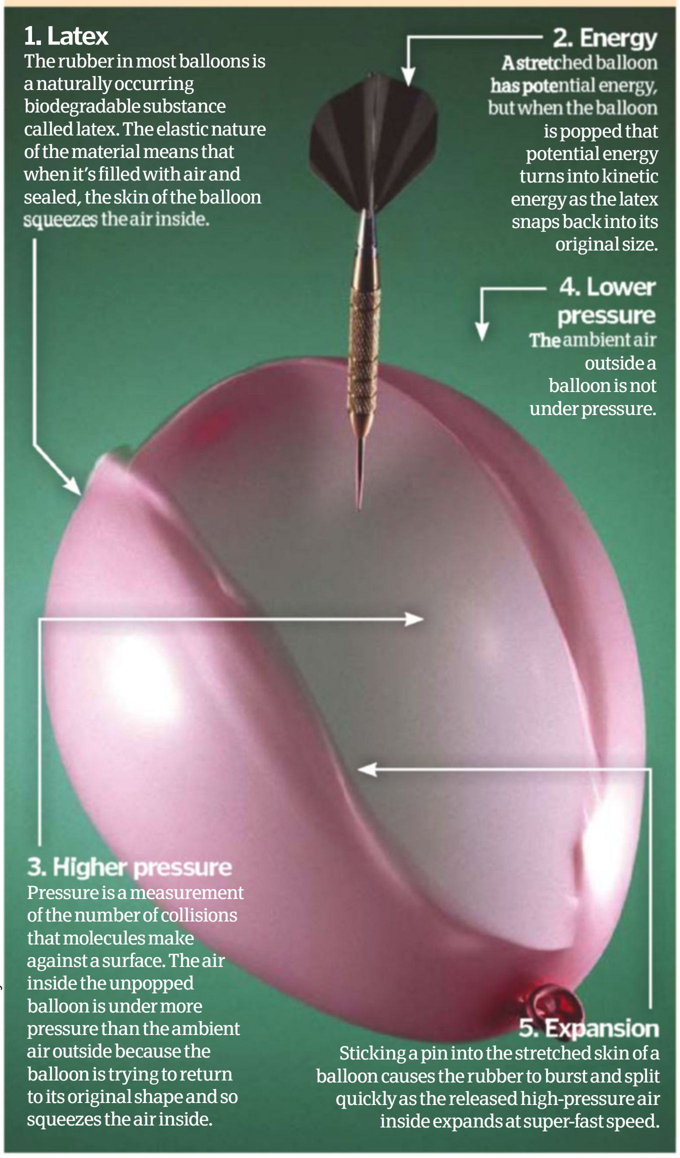
19
Number of genes: 2,066
Number of base pairs: 63 million
Associations and conditions: Leprechaunism, bleeding disorder, green/blue eye colour, late onset Alzheimer's disease, polio virus receptor, brown hair colour, epilepsy with febrile seizures, susceptibility to cerebral malaria and protection from nicotine addiction.

21
Number of genes: 450
Number of base pairs: 46 million
Associations and conditions: Chronic schizophrenia, influenza resistance, Down's syndrome, platelet disorder, T-cell lymphoma insensitivity and atypical mycobacterial infection.

Inside a balloon

Why does an inflated balloon go bang when popped?

When you start to blow into an empty balloon and the flexible latex material starts to expand, the chemical bonds holding its molecules together are permanently broken. If you blow too much air into the balloon, the latex will reach its elastic limit (the point at which it can no longer stretch) and the molecules will give way completely and rip apart at high speed. The compressed air inside the balloon will suddenly expand when the balloon is popped, forcing the hole in the latex balloon to widen extremely fast. The loud 'pop' occurs because the recoiling pieces of latex are moving faster than the speed of sound, producing a mini but nonetheless noisy sonic boom.



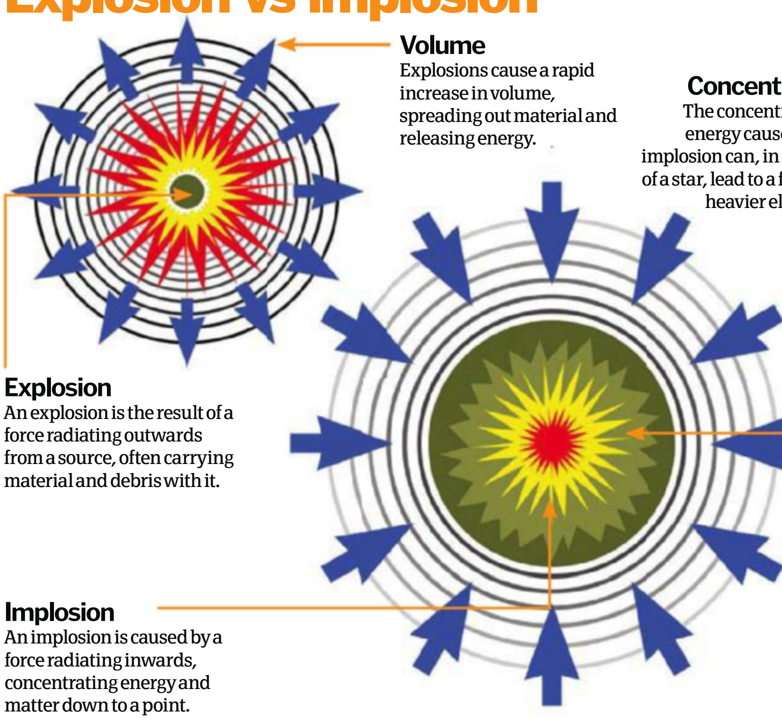
What is an implosion?

Is this crushing force really just the opposite of an explosion?

An implosion is the result of a force moving inwards to a point. It usually relies on an external environment having a much higher pressure, density or mass than the interior of an object or structure. An example would be a submarine. If the hull of a submarine were to breach, the weight of the water surrounding it would crush the submerged vehicle from the outside inwards.

A star will also implode before 'going supernova', as the mass and gravitational pull of its outer material eventually reaches a limit that will force it inwards, crushing the star from the outside in.

Explosion vs implosion



Volume
Explosions cause a rapid increase in volume, spreading out material and releasing energy.

Concentration
The concentration of energy caused by an implosion can, in the case of a star, lead to a fusion of heavier elements.

Explosion
An explosion is the result of a force radiating outwards from a source, often carrying material and debris with it.

Implosion
An implosion is caused by a force radiating inwards, concentrating energy and matter down to a point.

5 TOP FACTS WEIRD HEADACHE TRIGGERS

Relaxation
1 Relaxing after a period of anxiety can reduce the body's stress hormones. This causes the rapid release of chemical messages from the brain telling the blood vessels to constrict and dilate.

Strong smells
2 Being a chemical receptor, your nose can be affected by strong odours such as perfume and cleaning products. Inhaling these can trigger headache-causing circulatory changes.

Ice cream
3 'Brain freeze' is caused when something cold like ice cream in your mouth makes your body panic that the brain is freezing; blood vessels in the head rapidly dilate to heat it up.

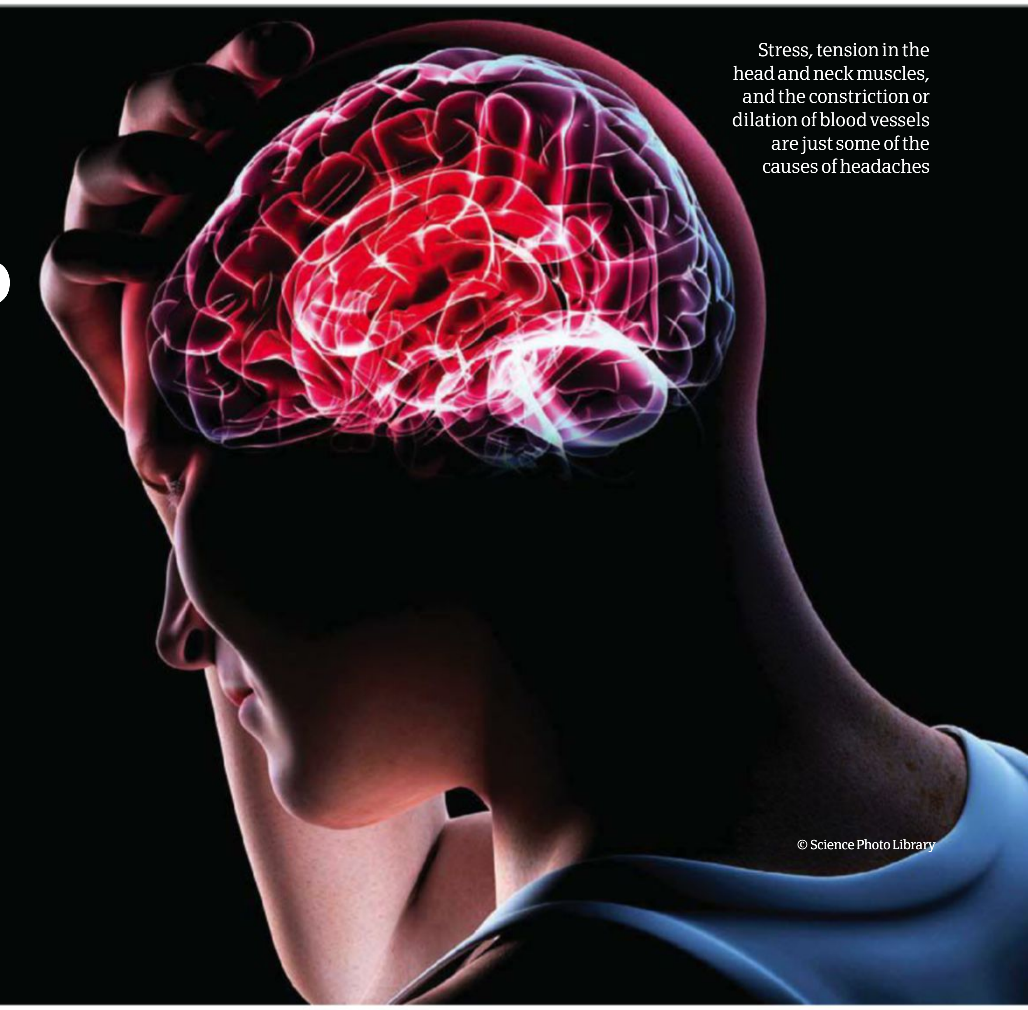
Anger
4 Try to stay calm if annoyed as when you get angry you experience tightness in the neck and scalp muscles. This can create a band of tension pain across the forehead.

Alcohol
5 Booze is known to cause dehydration, depleting the body's essential salts and minerals. This changes the chemical composition of the blood, which is something to which the brain is very sensitive.

DID YOU KNOW? A cluster headache is a severe primary headache that causes intense pain in a particular area

Why do we get headaches?

If the brain can't feel pain, why do headaches hurt so much?



Stress, tension in the head and neck muscles, and the constriction or dilation of blood vessels are just some of the causes of headaches

© Science Photo Library

The brain itself may not have any pain-sensitive nerve receptors, but that doesn't mean the inner head can't experience pain… as anyone who's had a headache will know.

The most common form of headache is the tension headache. When the muscles in your body stay semi-contracted for a period of time – for example, when we feel stressed and cannot seem to relax – this is known as muscle tension. Such tension in the meninges (the membranes that help protect the brain), or the face, neck and scalp muscles activate the body's pain receptors, sending impulses to the brain's sensory cortex and signalling pain, and thus causing a headache.

More frequent in women than men, the primary tension-type headache manifests itself as a dull ache across both sides of the head. Secondary headaches, meanwhile, can be caused by an underlying health condition such as meningitis, a blow to the head or other sinus-related ailments.

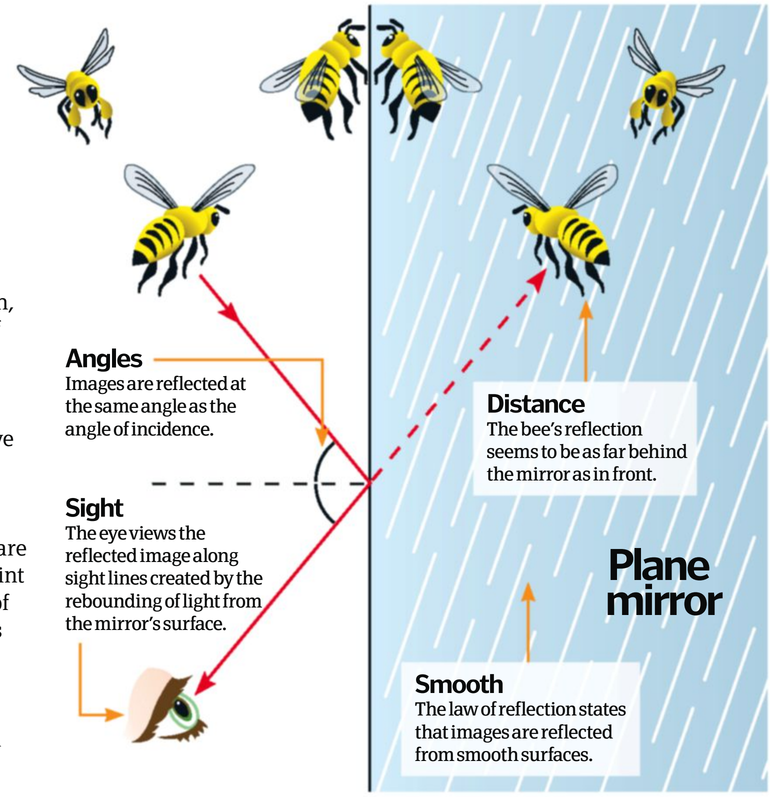
Mirrors

We reflect on the laws that ensure these objects never lie

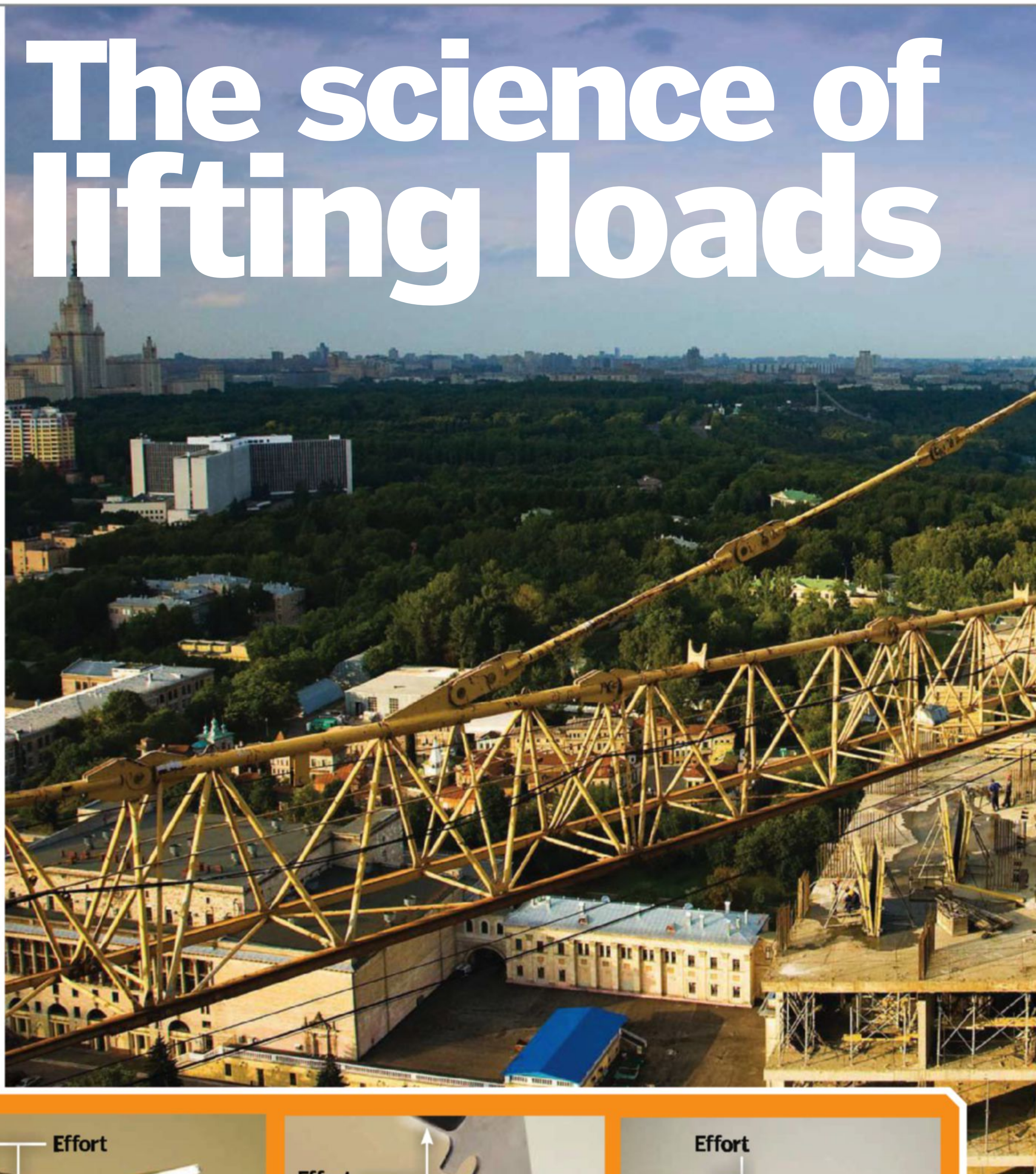
Mirrors are characterised as any polished surface that diverts light rays according to the law of reflection, which states that the angle of incidence is equal to the angle of reflection. When light rays fall on a mirror it reflects more rays than it absorbs, and due to its perfectly smooth surfaces, it does so without scattering or diffusing the reflected rays.

There are two main types of mirror – plane and curved – the latter being further broken down into concave and convex varieties. Plane mirrors are the most common type and are frequently used as tools that we can directly use to view ourselves without distortion, ie producing a mirror image. Plane mirrors do this as when parallel beams of light hit them they change direction as a whole according to the law of reflection, producing a virtual, reflected image of the same size as the original object visible within their boundaries.

The reflected images produced by curved mirrors differ however. Concave mirrors reflect received light rays inwards towards a single focal point, instead of directly parallel as in plane mirrors. This is because the light rays are reflected at different angles at each point of contact with the inward curvature of the mirror. In contrast, convex mirrors achieve the opposite effect, reflecting light outwards. This is because their focal point is technically positioned 'inside' the mirror, forcing the parallel beams to become divergent at a common, virtual intersection.



The science of lifting loads



How do levers, gears and pulleys work?

Lifting loads is based on fundamental physical concepts that involve forces and motion. Levers, gears and pulleys work by transferring a force from one place to another, usually magnifying it but occasionally minimising it for reasons explained later. These types of lifting are known as a mechanical advantage, increasing or decreasing the force by a certain factor.

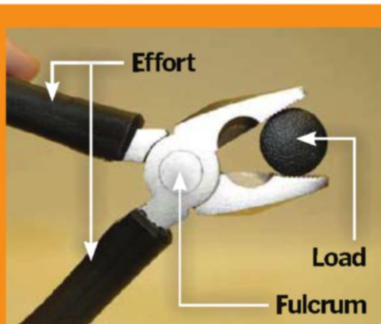
Every object – indeed every particle – is attracted towards Earth by the force of gravity, with this force corresponding to a downwards acceleration of 9.81m/s². Every object also has a centre of gravity, which is the point where the majority of its weight is acting downwards. For a load to be lifted it must be balanced about this centre of gravity. Attempting to lift it at any other point will result in it tilting or falling over.

Any stationary object is said to be at rest and in static equilibrium, with all forces on it balanced. Applying a force to lift the object brings it out of balance. Newton's Third Law of Motion states that all actions have an equal and opposite reaction. Therefore, lifting a load upwards with a certain force exerts an equal force downwards in opposite measure. Levers, gears and pulleys overcome this problem by magnifying the lifting force applied. The further the effort is from the load, the greater the force that will be experienced by the latter. Here you'll see how each of these ancient mechanical systems gets its advantage.

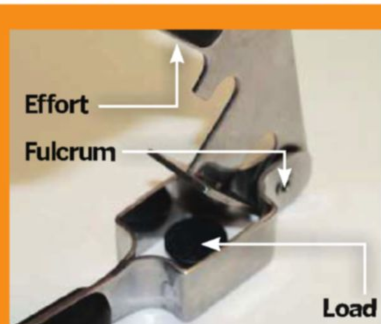
Levers

There are three types of lever that can produce a magnified lifting force. Levers always turn on a pivot, which is also known as the fulcrum. Effort is the place at which the initial force is applied, and the load is the object that is either to be lifted or broken. Different levers use different placement of effort, load and the fulcrum to perform the required task.

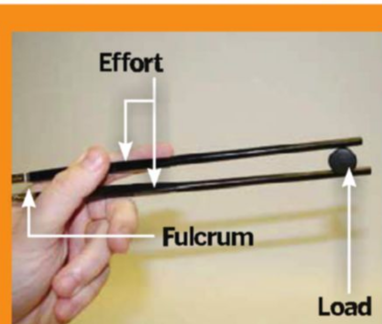
The load is the object that is trying to be moved, the effort is the force applied to move this load and the fulcrum is the point at which the load is pivoted.



First-class lever
First-class levers – as seen in everyday objects such as see-saws and pliers – have their effort and load positioned at opposite ends of the fulcrum. The greater distance between these allows more of the force to be transferred to the load. This is because more effort must be applied to the load, and thus the system magnifies the force.



Second-class lever
On the other hand, in a second-class lever – a nutcracker being one prime example – the effort and load are on the same side of the fulcrum; however they are applied in opposite directions. Like first-class levers, the effort is magnified but the closer distance between the effort/load means that there is greater control about the fulcrum.

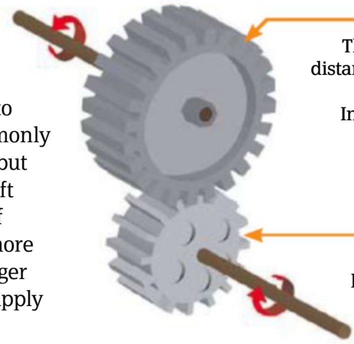


Third-class lever
This works in the opposite way to first- and second-class levers, reducing the force applied on the load compared to the effort, as seen in tools such as tweezers and chopsticks. Here, the effort is between the load and the fulcrum, but the force applied is greater than that on the load. The lever magnifies the distance the force has to travel, so reduces the force on the load.

DID YOU KNOW? Nail clippers, scales and piano keys are all compound levers, which combine the forces of two or more levers

Gears

Gears transfer turning motion from one point to another. They are commonly used in watchmaking, but can also be applied to lift large loads. The teeth of gears fit together. The more teeth a gear has, the larger a turning force it will supply to a smaller gear.



1. Pitch
The pitch of a gear is the distance between the same point on two teeth. Interlocking gears must have the same pitch.

2. Ratio
The more teeth a gear has, the larger turning force it will supply to a smaller gear.

Basic pulley physics

The first diagram in the 'Pulleys' boxout shows a single pulley with a weight at one end of the rope. The other end is held by a person who must apply a force to keep the weight hanging in the air (in equilibrium).

There is a force (tension) in the rope that is equal to the weight of the object. This force, or tension, is the same all along the rope. In order for the weight and pulley (the system) to remain in equilibrium, the person holding the rope must pull down with a force equal in magnitude to the tension in the rope. For this pulley system, the force is equal to the weight, ie 100N. The mechanical advantage of this system is one.

In the second figure, the pulley is movable. As the rope is pulled up, the pulley can also rise. The weight is attached to this movable pulley. Here the weight is supported by both the rope end attached to the upper bar and the end held by the person. Each side of the rope is supporting the weight, so carries only half the load (two upward tensions are equal and opposite to the downward weight, so each tension is equal to half the weight). So the force needed to hold up the pulley in this example is half the load. The mechanical advantage of this system is two; it is the weight (output force) divided by half the weight (input force).

Each figure below shows different possible pulley combinations using both fixed and movable pulleys. The mechanical advantage of each system is easy to determine. Count the number of rope/cable segments on each side of the pulleys, including the free end. If the free end is to be pulled down, subtract one from this number. The resulting value is the mechanical advantage of the system. To compute the amount of force needed to hold the weight in equilibrium, you divide the weight by this mechanical advantage.

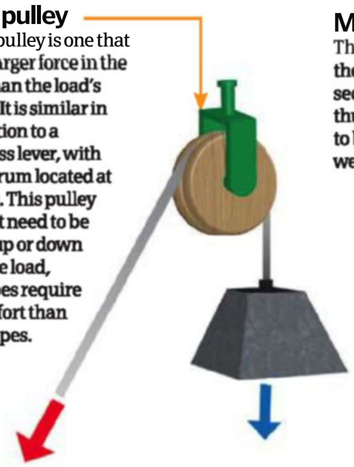
In the final pulley example there are three sections of rope. Since the applied force is downward, we subtract one for a mechanical advantage of two. It will take a force equal to half the weight to hold the load steady. This figure has the same two pulleys, but the rope is applied differently and it is pulled upwards. The mechanical advantage is three, and the force needed in order to gain equilibrium is one-third of the load.

Pulleys

A pulley is a machine that uses a rope, belt or chain wrapped around a wheel to lift a heavy load. By changing the direction of the force, and the distance from the effort to load, pulleys ultimately make lifting a load much easier. There are three main types of pulley, as shown here.

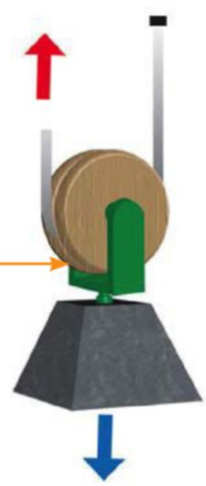
Fixed pulley

A fixed pulley is one that uses a larger force in the effort than the load's weight. It is similar in application to a first-class lever, with the fulcrum located at the axis. This pulley does not need to be pulled up or down to lift the load, but it does require more effort than other types.



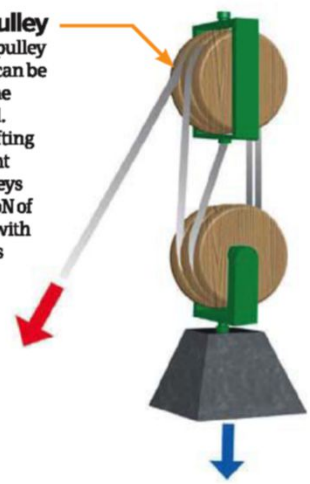
Movable pulley

This pulley moves with the load, acting as a second-class lever and thus allowing the effort to be less than the weight of the load.

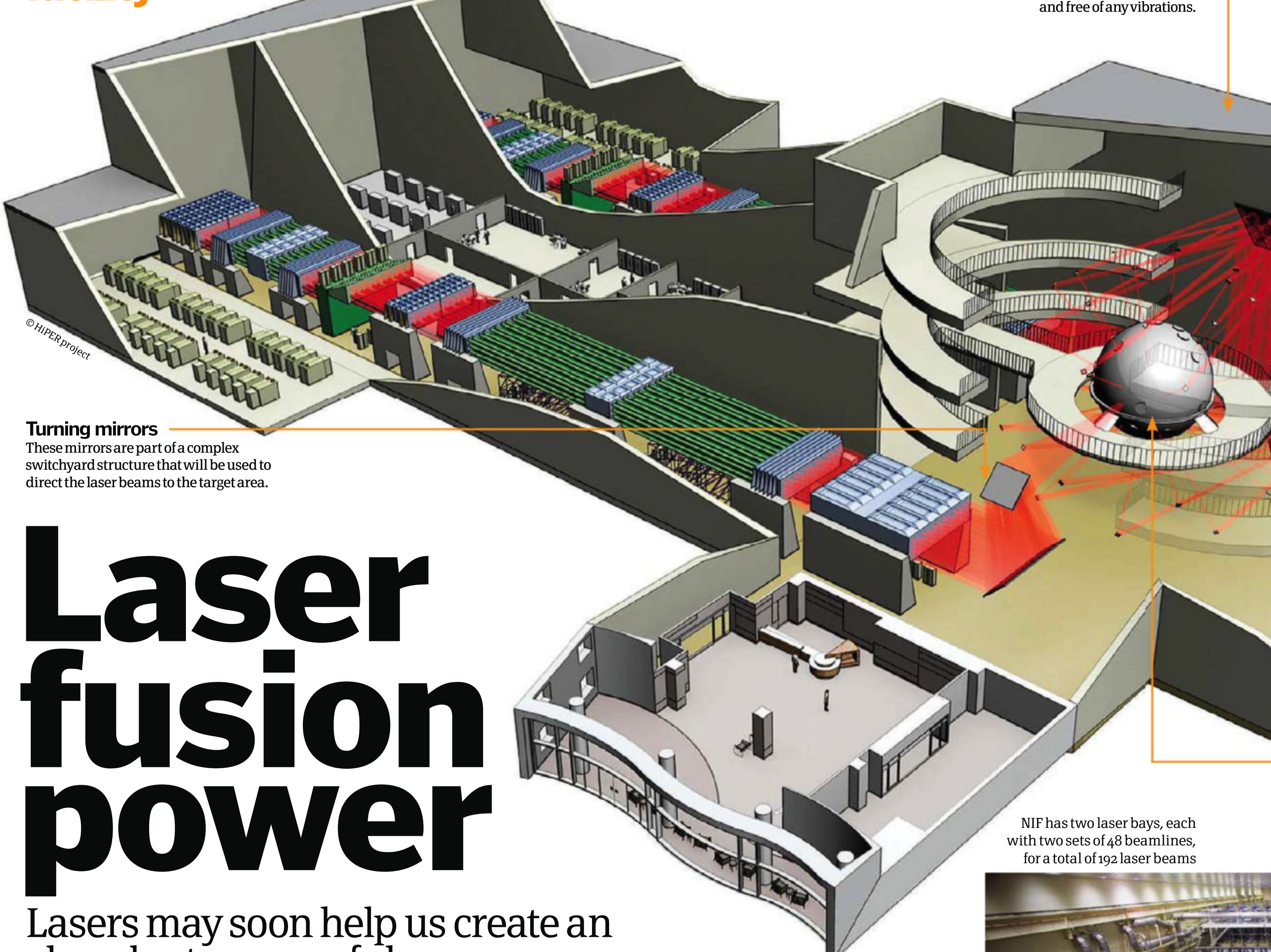


Combined pulley

Adding a second pulley means the effort can be much less than the weight of the load. As an example, lifting an object of weight 150N with no pulleys would require 150N of force (effort), but with two pulleys this is reduced to 50N.



Proposed HiPER facility



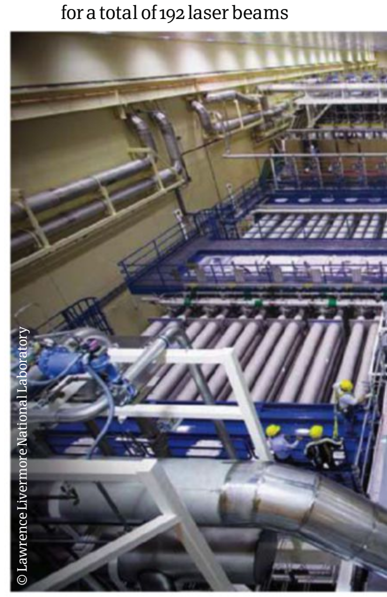
Laser fusion power

Lasers may soon help us create an abundant source of clean energy

The idea of using laser fusion to generate energy has been around for several decades, but until recently technological limitations have kept it from being a viable source of alternative power. Also known as inertial confinement fusion (ICF), this process generates energy by using lasers to compress and heat fuel, resulting in nuclear fusion reactions. Not only do the lasers have to generate significant heat on their own, but they also have to be precisely focused on the fuel source and capable of delivering consistent, spherical beams. The ultimate goal is to create ignition, a chain reaction that burns up most or all of the fuel and can generate the energy equivalent of a barrel of oil. Ideally a laser fusion plant would be able to produce just as much energy as a coal plant of comparable size, but cheaper and with far less pollution.

There have been numerous experimental laser fusion facilities over the past several decades. The National Ignition Facility (NIF), located in California, completed its first experiments in October 2010. They used laser beams to heat a hollow chamber called a hohlraum, which contains a two-millimetre (0.08-inch) pellet of fuel containing deuterium and tritium (both readily available hydrogen isotopes that can be isolated from seawater). This is known as the indirect drive method – the cylinder heats and emits x-rays that are more symmetrical and consistent than the original laser beams, which heat and compress the actual fuel. The European Union has been planning its own laser fusion facility, known as HiPER (High Power laser Energy Research). The hope is that it will begin demonstrations within the next few years.

NIF has two laser bays, each with two sets of 48 beamlines, for a total of 192 laser beams



THE STATS
HiPER IN NUMBERS

LASER TEMPERATURE **100 million°C**

LARGEST LASER LENGTH **329m (1,079ft)**

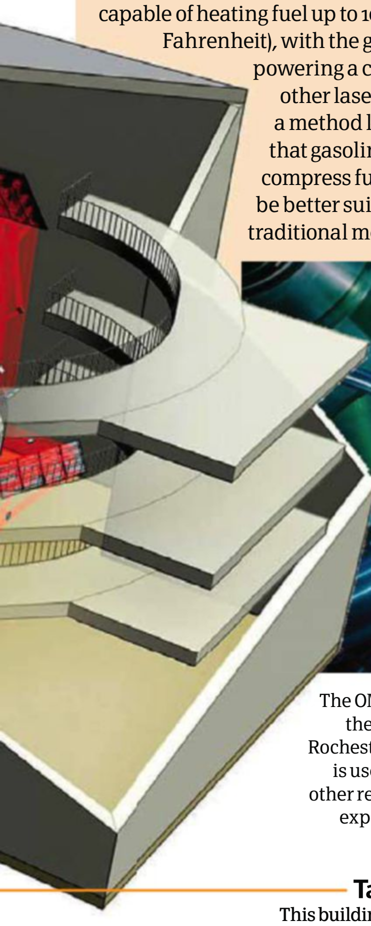
PEAK ENERGY OUTPUT **4 trillion joules**

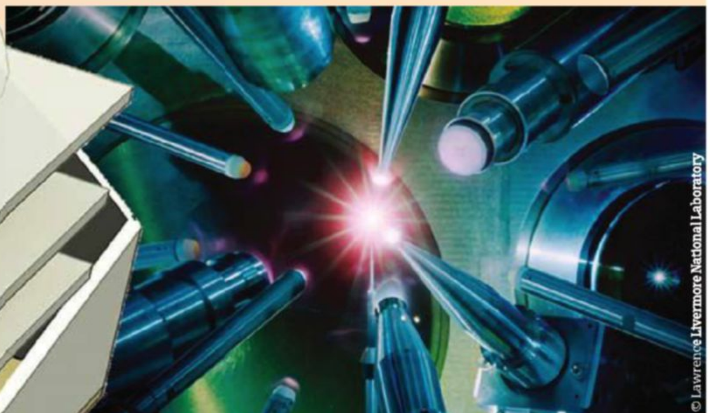
NUMBER OF LASER GLASS PLATES **3,070**

DID YOU KNOW? *Laser fusion can be seen as creating a star smaller than a hair, which dies within 200 trillionths of a second*

The HiPER project

The HiPER project proposes to use very small amounts of fuel, heated at extremely high temperatures, to release enormous amounts of energy. To cause chain fusion reactions, the fuel must be heated and compressed very quickly. Estimates are that there will be five to ten reactions per second. To this end, the laser that HiPER will use needs to be capable of heating fuel up to 100 million degrees Celsius (180 million degrees Fahrenheit), with the goal of putting out a non-stop flow of electricity capable of powering a conventional power station. HiPER differs from NIF and other laser fusion facilities because it will be civilian-based and use a method known as 'fast ignition' – described as similar to the way that gasoline-powered engines use spark plugs for ignition and compress fuel. This method is supposed to require a smaller laser and be better suited to commercial energy production than the more traditional method being tested at NIF.

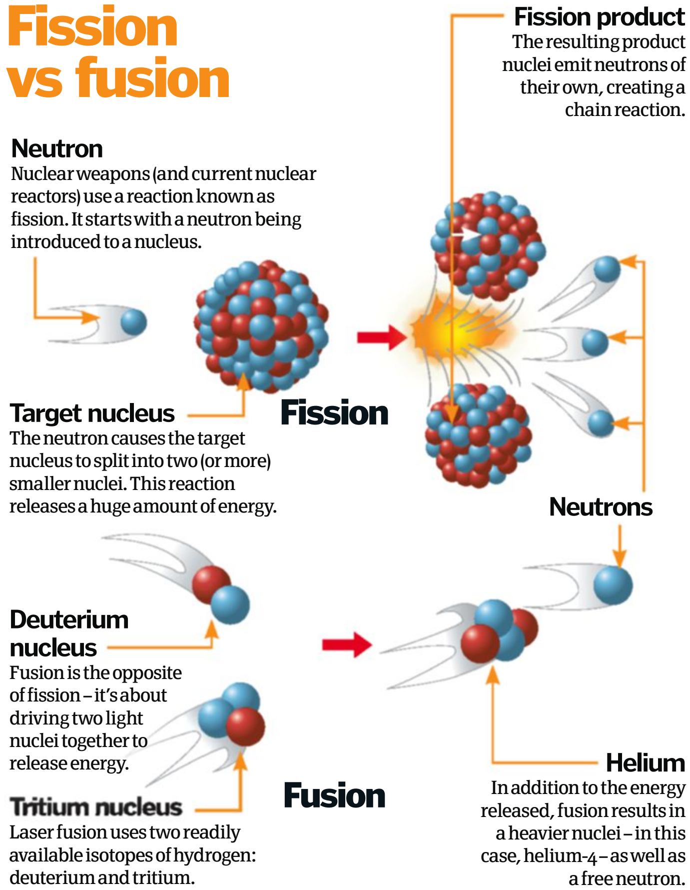


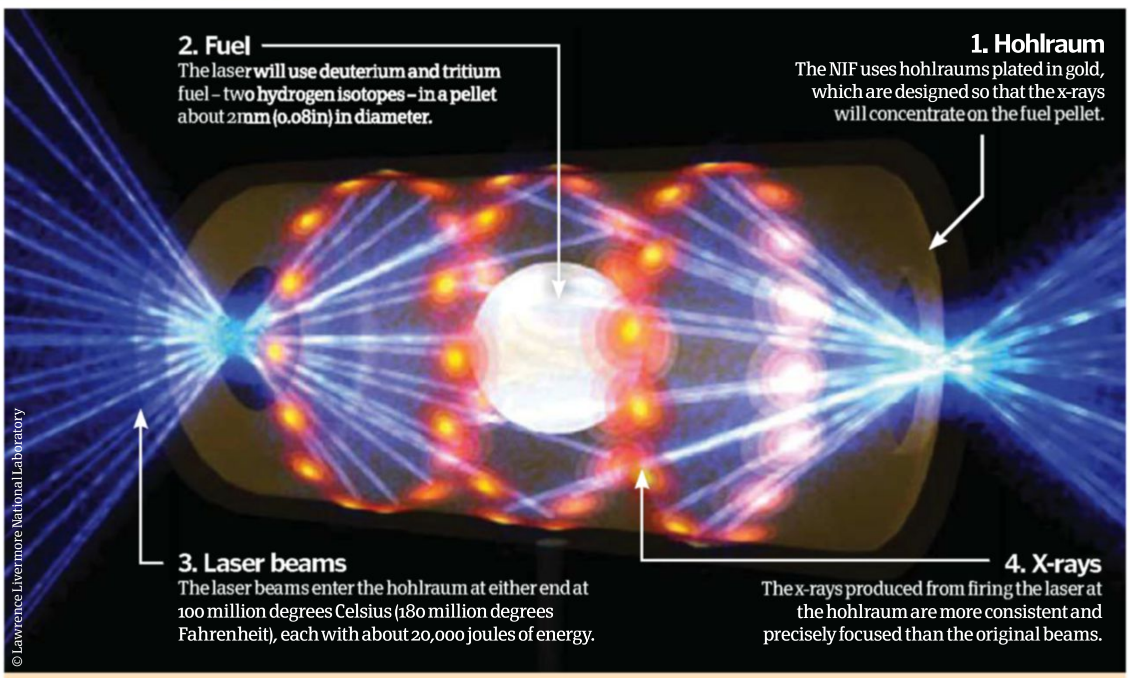


The OMEGA laser at the University of Rochester, New York, is used by NIF and other researchers for experimentation and testing

Target area
This building is designed to house four target areas, including a ten-metre (33-foot)-wide fusion target chamber.

Fission vs fusion





The hohlraum capsule

The laser fusion process at NIF uses the indirect method to heat and compress fuel, triggering a nuclear reaction. A chamber known as a hohlraum (German for 'empty cavity') houses the fuel source. Laser beams – 192 of them in the case of the NIF laser – are directed inside the chamber, which absorbs the energy, heats it to a super-hot plasma and redirects it as thermal x-rays. The x-rays and ensuing shock waves strike the fuel pellet in the centre, heating it until it implodes, generating up to 100 times the energy emitted by the laser beams.

Cell structure explained

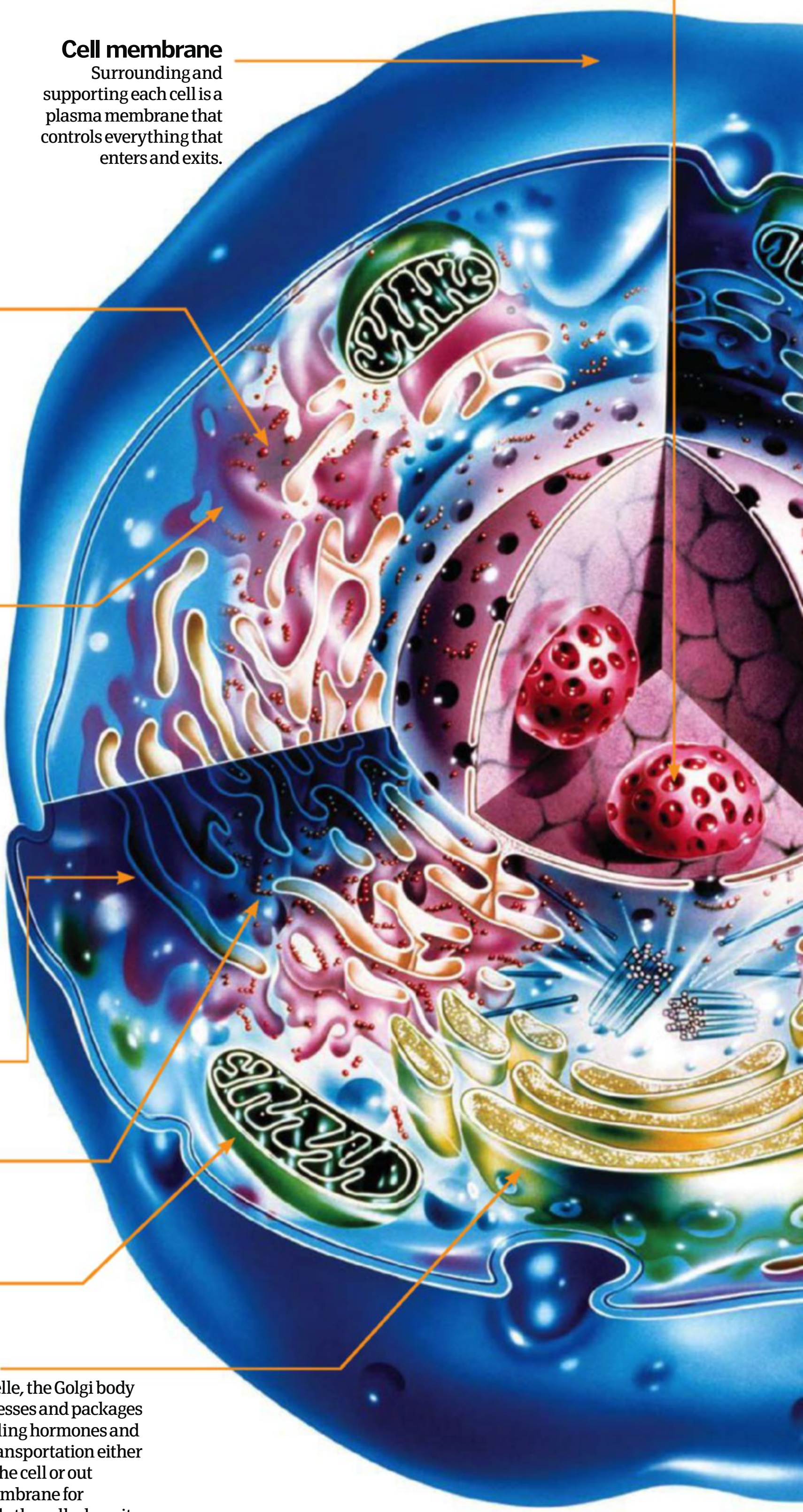
There are around 75 trillion cells in the human body, but what are they and how do they work?

Cells are life and cells are alive. You are here because every cell inside your body has a specific function and a very specialised job to do. There are many different types of cell, each one working to keep the body's various systems operating. A single cell is the smallest unit of living material in the body capable of life. When grouped together in layers or clusters, however, cells with similar jobs to do form tissue, such as skin or muscle. To keep these cells working, there are thousands of chemical reactions going on all the time.

All animal cells contain a nucleus, which acts like a control hub telling the cell what to do and contains the cell's genetic information (DNA). Most of the material within a cell is a watery, jelly-like substance called cytoplasm (cyto means cell), which circulates around the cell and is held in by a thin external membrane, which consists of two layers. Within the cytoplasm is a variety of structures called organelles, which all have different tasks, such as manufacturing proteins – the cell's key chemicals. One vital example of an organelle is a ribosome; these numerous structures can be found either floating around in the cytoplasm or attached to internal membranes. Ribosomes are crucial in the production of proteins from amino acids.

In turn, proteins are essential to building your cells and carrying out the biochemical reactions the body needs in order to grow and develop and also to repair itself and heal.

Cell anatomy



Cell membrane
Surrounding and supporting each cell is a plasma membrane that controls everything that enters and exits.

Ribosomes
These tiny structures make proteins and can be found either floating in the cytoplasm or attached like studs to the endoplasmic reticulum, which is a conveyor belt-like membrane that transports proteins around the cell.

Endoplasmic reticulum
The groups of folded membranes (canals) connecting the nucleus to the cytoplasm are called the endoplasmic reticulum (ER). If studded with ribosomes the ER is referred to as 'rough' ER; if not it is known as 'smooth' ER. Both help transport materials around the cell but also have differing functions.

Smooth endoplasmic reticulum

Rough endoplasmic reticulum (studded with ribosomes)

Mitochondria
These organelles supply cells with the energy necessary for them to carry out their functions. The amount of energy used by a cell is measured in molecules of adenosine triphosphate (ATP). Mitochondria use the products of glucose metabolism as fuel to produce the ATP.

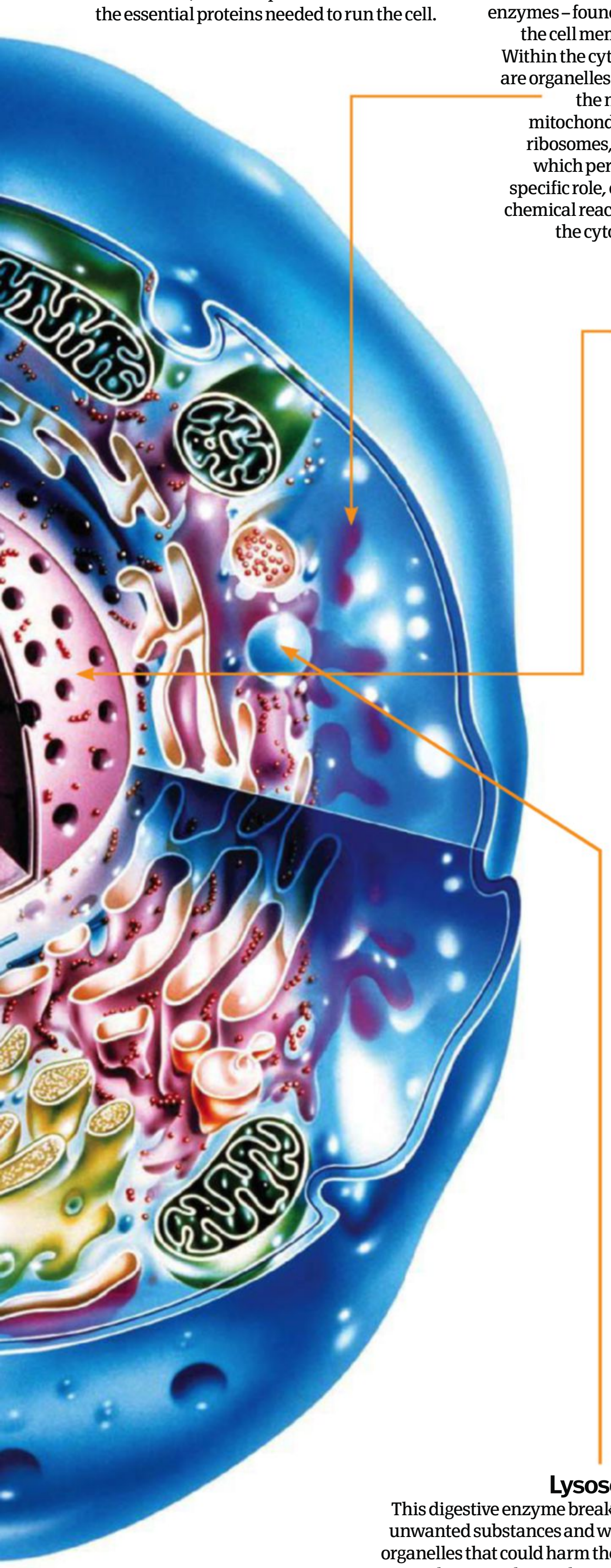
Golgi body
Another organelle, the Golgi body is one that processes and packages proteins, including hormones and enzymes, for transportation either in and around the cell or out towards the membrane for secretion outside the cell where it can enter the bloodstream.

DID YOU KNOW?

Super cells

Stem cells are self-renewing wonder cells with the potential to become any other type of cell in the body. Unlike regular cells, they do not have a specialisation, such as nerve cells. All cells start out as stem cells, before developing specific skills. Lab experts have discovered that adult stem cells can be manipulated into other types with the potential to grow replacement organs in the lab.

DID YOU KNOW? *Bacteria are the simplest living cells and the most widespread life form on Earth*



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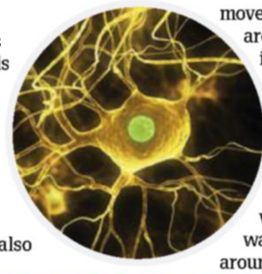
Types of human cell

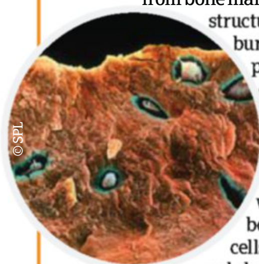
So far around 200 different varieties of cell have been identified, and they all have a very specific function to perform. Discover the main types and what they do...

NERVE CELLS



The cells that make up the nervous system and the brain are nerve cells or neurons. Electrical messages pass between nerve cells along long filaments called axons. To cross the gaps between nerve cells (the synapse) that electrical signal is converted into a chemical signal. These cells enable us to feel sensations, such as pain, and they also enable us to move.

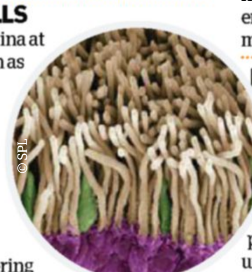
BONE CELLS



© SPL

The cells that make up bone matrix – the hard structure that makes bones strong – consist of three main types. Your bone mass is constantly changing and reforming and each of the three bone cells plays its part in this process. First the osteoblasts, which come from bone marrow, build up bone mass and structure. These cells then become buried in the matrix at which point they become known as osteocytes. Osteocytes make up around 90 per cent of the cells in your skeleton and are responsible for maintaining the bone material. Finally, while the osteoblasts add to bone mass, osteoclasts are the cells capable of dissolving bone and changing its mass.

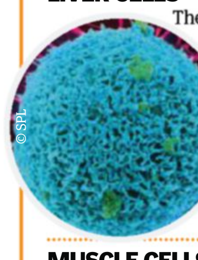
PHOTORECEPTOR CELLS



© SPL

The cones and rods on the retina at the back of the eye are known as photoreceptor cells. These contain light-sensitive pigments that convert the image that enters the eye into nerve signals, which the brain interprets as pictures. The rods enable you to perceive light, dark and movement, while the cones bring colour to your world.

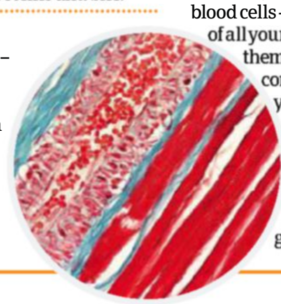
LIVER CELLS



© SPL

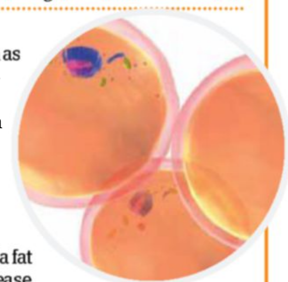
The cells in your liver are responsible for regulating the composition of your blood. These cells filter out toxins as well as controlling fat, sugar and amino acid levels. Around 80 per cent of the liver's mass consists of hepatocytes, which are the liver's specialised cells that are involved with the production of proteins and bile.

MUSCLE CELLS



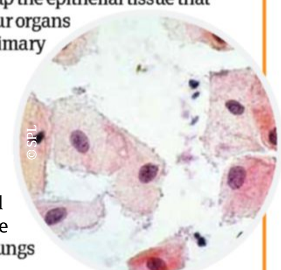
There are three types of muscle cell – skeletal, cardiac and smooth – and each differs depending on the function it performs and its location in the body. Skeletal muscles contain long fibres that attach to bone. When triggered by a nerve signal, the muscle contracts and pulls the bone with it, making you move. We can control skeletal muscles because they are voluntary. Cardiac muscles, meanwhile, are involuntary, which is fortunate because they are used to keep your heart beating. Found in the walls of the heart, these muscles create their own stimuli to contract without input from the brain. Smooth muscles, which are pretty slow and also involuntary, make up the linings of hollow structures such as blood vessels and your digestive tract. Their wave-like contraction aids the transport of blood around the body and the digestion of food.

FAT CELLS



These cells – also known as adipocytes or lipocytes – make up your adipose tissue, or body fat, which can cushion, insulate and protect the body. This tissue is found beneath your skin and also surrounding your other organs. The size of a fat cell can increase or decrease depending on the amount of energy it stores. If we gain weight the cells fill with more watery fat, and eventually the number of fat cells will begin to increase. There are two types of adipose tissue: white and brown. The white adipose tissue stores energy and insulates the body by maintaining body heat. The brown adipose tissue, on the other hand, can actually create heat and isn't burned for energy – this is why animals are able to hibernate for months on end without food.

EPITHELIAL CELLS



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Epithelial cells make up the epithelial tissue that lines and protects your organs and constitute the primary material of your skin. These tissues form a barrier between the precious organs and unwanted pathogens or other fluids. As well as covering your skin, you'll find epithelial cells inside your nose, around your lungs and in your mouth.

RED BLOOD CELLS

Unlike all the other cells in your body, your red blood cells (also known as erythrocytes) do not contain a nucleus. You are topped up with around 25 trillion red blood cells – that's a third of all your cells, making them the most common cell in your body. Formed in the bone marrow, these cells are important because they carry oxygen to all the tissues in your body. Oxygen is carried in haemoglobin, a pigmented protein that gives blood cells their red colour.

Blood clotting

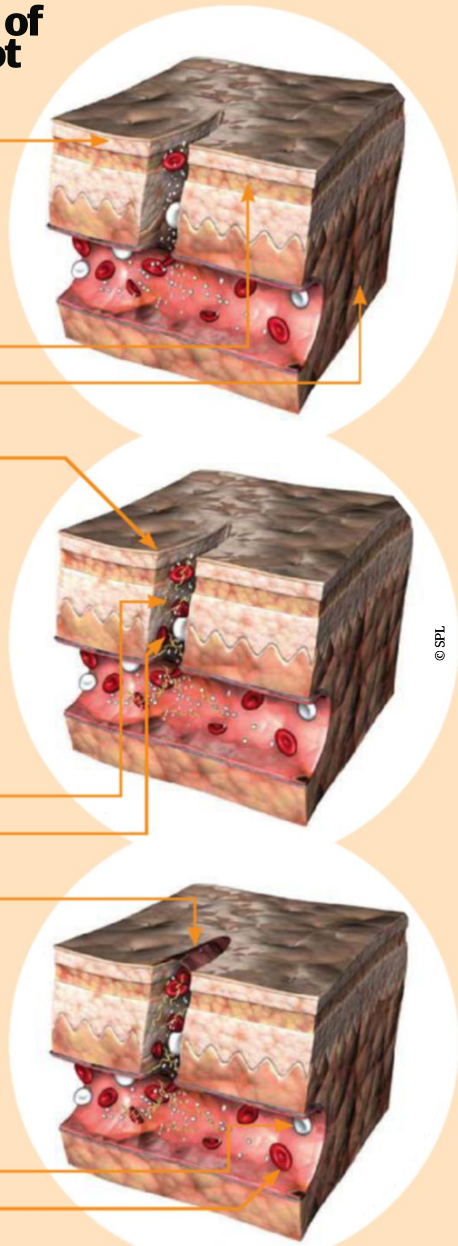
How the body reacts to blood vessel damage to aid the healing process

Through the action of the thrombin system, coagulation of the blood occurs instantly at the location where there is a cut or other injury to the skin. The blood clot, which consists of a combination of cellular platelets and sticky strings of fibrin, forms a plug in the damaged blood vessels.

The clot stops blood from freely flowing out of the body and at the same time allows the blood to continue circulating. As the skin heals, plasmin enzymes break down the webs of fibrin and the clot is eventually dissolved into the body.

Clots can also form in blood vessels due to inactivity, old age, obesity, smoking, poor diet or during pregnancy. This condition is known as thrombosis and can lead to an embolism.

Formation of a blood clot



1. Skin layer
Composed of a water-resistant and protective layer called the epidermis; beneath it is the dermis layer that consists of blood vessels and connective tissue.

Epidermis

Dermis

2. Cut
If skin is cut, platelets in the blood vessels of the damaged area become 'sticky' and clump together at the damaged site to form a white clot. Other chemical reactions create sticky web-like strands of fibrin that adhere to the damaged blood vessel wall, to form a red clot.

Strands of fibrin

Platelets

3. Healing
The blood clot stops blood escaping from the wound, and allows the normal circulation of the red blood cells which transport oxygen around the body and the white blood cells that protect it against infection.

White blood cell

Red blood cell

© SPL

The owner of this building will think twice before putting off the housework next time

Deadly dust explosions

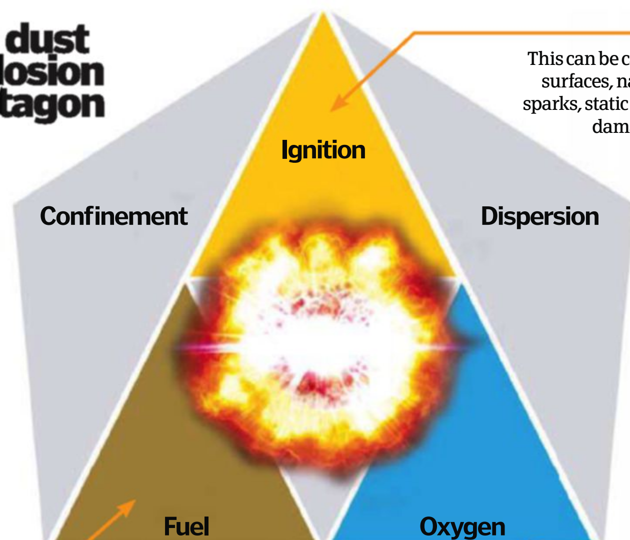
Never underestimate the dangers of dust

You may think dust is harmless dirt, but the nature of this substance makes it potentially lethal in certain circumstances. Virtually any combustible and even some non-combustible materials can pose an explosion hazard when in a fine powdered state.

Generally, dust that is 420 microns or less in diameter is most likely to cause an explosion, depending on its moisture content, shape and size combined with the type of processing equipment it's used or created by. Danger levels increase with nearby heat sources and where dust can accumulate in confined spaces.

Manufacturing companies use filtering equipment, ventilation systems and good housekeeping methods to help prevent dust explosions occurring.

The dust explosion pentagon



Heat
This can be caused by hot surfaces, naked flames, sparks, static electricity or damaged wiring.

Fuel
There has to be a sufficient amount of dust to fuel the explosion, and this varies according to the type of dust involved. Compared to solid material, dust requires less energy to ignite and presents a larger surface area to interact with oxygen making it far more flammable and dangerous.

Oxygen
Air (or more specifically oxygen) will keep the fuel (dust) burning and if it is in a confined area of a factory, warehouse or silo where dust dispersion is very low it can quickly lead to an explosion. The primary explosion can lead to the detonation of dust elsewhere in the area.

DID YOU KNOW?


©MichaelMaggs

How is the cue ball separated?

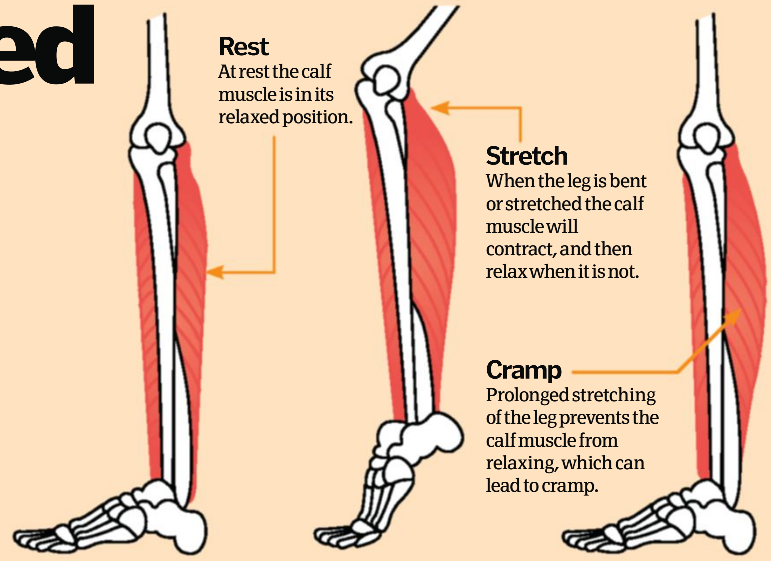
When the cue ball falls into the pocket of an auto-dispensing table it is separated from the other balls by one of two methods. It is either a couple of millimetres larger so that it feeds into a different tunnel, or it contains a magnetic material and is drawn to a separate area by magnets.

DID YOU KNOW? *Writers' cramp occurs in the hands and lower arms but is actually a form of dystonia, a neurological condition*

Cramp explained

Why do our muscles tense up?

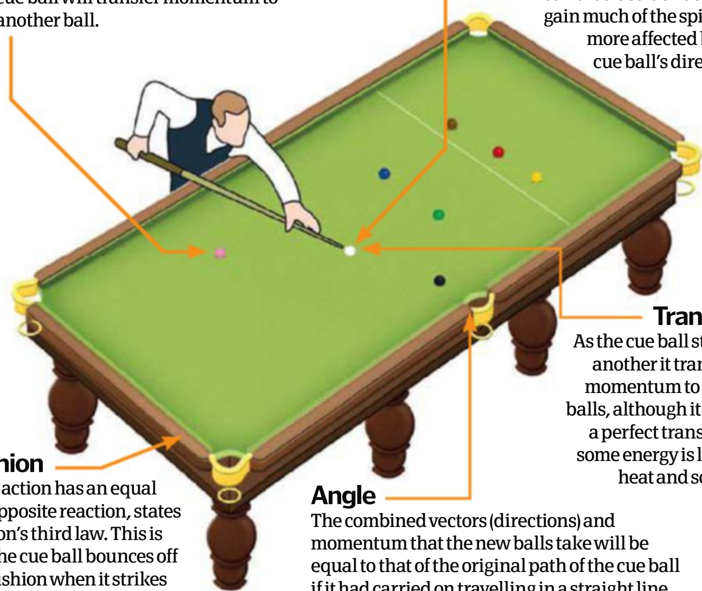
Cramp is an involuntary contraction of a muscle, often in a limb such as the leg, that can cause pain and discomfort for seconds, minutes or, in extreme cases, for several hours. They are most common after or during exercise, coinciding with low blood sugar levels, dehydration and a high loss of salt from sweating. Although the full range of causes is something of a mystery due to limited research in the area, cramp is believed to be the result of muscle fatigue. If a muscle has been shortened through prolonged use but is repeatedly stimulated, it isn't able to properly relax. A reflex arc from the central nervous system to the muscle informs it to continue contracting when it is not necessary, leading to a painful spasm known as cramp as the muscle continually attempts to contract. This is why athletes pushed beyond their limits, such as football players who have to play extra time in a soccer match, and long-distance runners, will often experience this condition.



Science of pool

How Newton's laws govern this popular sport

There's plenty of science that determines how both amateur and professional players are able to control the balls in the games of snooker and pool. Momentum, energy, inertia and the fundamental laws of physics all play a part in determining the motion of balls around the table. Take a look at our diagrams to get an in-depth understanding of the science behind these games that are played the world over.

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Fool's gold

Why is this widespread mineral often mistaken for the precious metal?

Iron pyrite – also known as fool's gold due to its similar colouration to the precious metal – is one of the commonest minerals on the planet. All Earth's rocks are made up of minerals, and pyrite belongs to a large group known as the sulphides. Pyrite occurs in most environments and in sedimentary, igneous and metamorphic rocks. Fool's gold contains a mixture of mostly iron and sulphur, as well as occasionally featuring trace amounts of nickel, silver and gold. When iron and sulphur are heated and pressurised underground, iron pyrite forms into a distinctive crystalline structure. While it might look a bit like gold, fool's gold is actually lighter, harder and more brittle.

Friction in action

This powerful force affects almost every facet of your day-to-day life. Here, you'll learn what friction is, the science behind it and how it can be countered

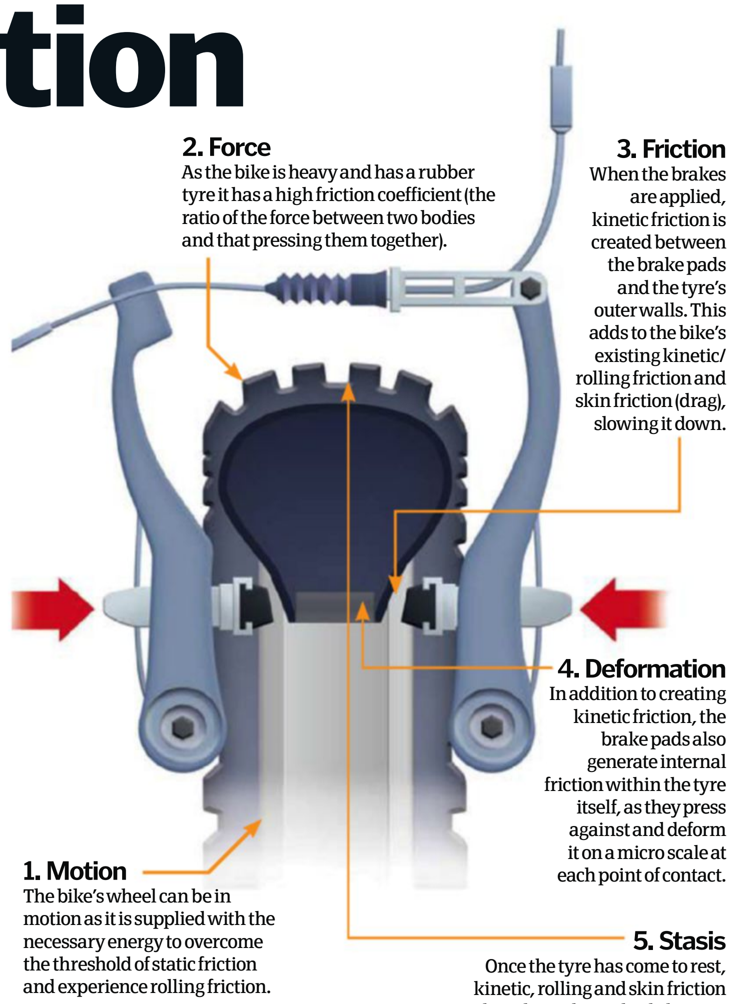
Friction is characterised as the force resisting the relative motion of solid surfaces and fluid (ie air and water) layers. For example, when rolling a ball along a flat floor it will slowly come to a stop, as its forward momentum is overcome by friction. This is because at every point of contact between the ball's surface and the floor, its kinetic energy is gradually being sapped by deformation and skin friction (or drag). As such, friction is a force that can be highly beneficial, as when preventing humans from losing traction on flat and steep terrain, as well as a hindrance – for example, when reducing the acceleration of a vehicle.

The overall force of friction is dependent on the magnitude of the perpendicular forces of the surfaces in contact. These forces are referred to as the normal force (the net force compressing the two surfaces together; in an everyday context this is usually gravity/weight) and the frictional force, with the ratio between the two known as the friction coefficient. The coefficient of friction is determined by the material properties of the two touching surfaces. So, for example, steel blades coming into contact with an ice rink generate a low friction coefficient, while rubber tyres on tarmac produce a high one.

There are many types of friction – see 'Types of friction' boxout – however the most fundamental forms are static and kinetic (often grouped together as 'dry friction'). A good example of both and how they work can be seen by placing a brick on a flat table. At rest the brick is experiencing static friction, which is at a force equal to that necessary to prevent motion between the surfaces. When an auxiliary force, however, is applied to the brick – such as it being pushed/pulled – provided it is of a magnitude greater than that of the static friction, it moves, experiencing kinetic friction.

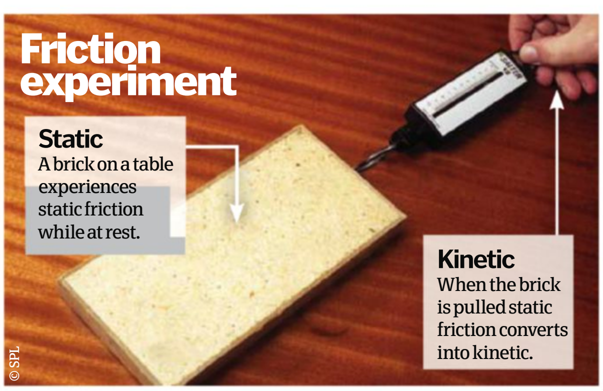
The effects can be mitigated by altering the type of friction generated to one with a lower friction coefficient. For example, by placing a lubricant between two solid surfaces – such as the brick and table – dry friction can be converted into lubricated friction, reducing the overall force that's needed to move it.

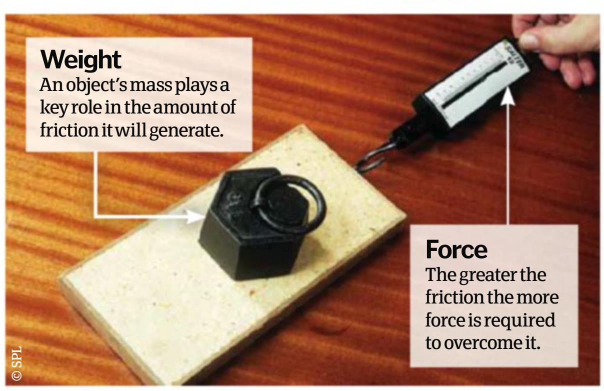
Another good example of this process can be seen in ball bearings. Here, by the addition of spherical balls in between two rotating mechanical parts of a machine, rolling friction can be produced in place of kinetic. This grants a far lower friction coefficient and reduces friction-caused wear, and so shrinks the amount of energy needed to set, and keep, an object in motion.



F1 cars often have slick tyres that have no tread at all, limiting friction between the vehicle and the track

Friction experiment

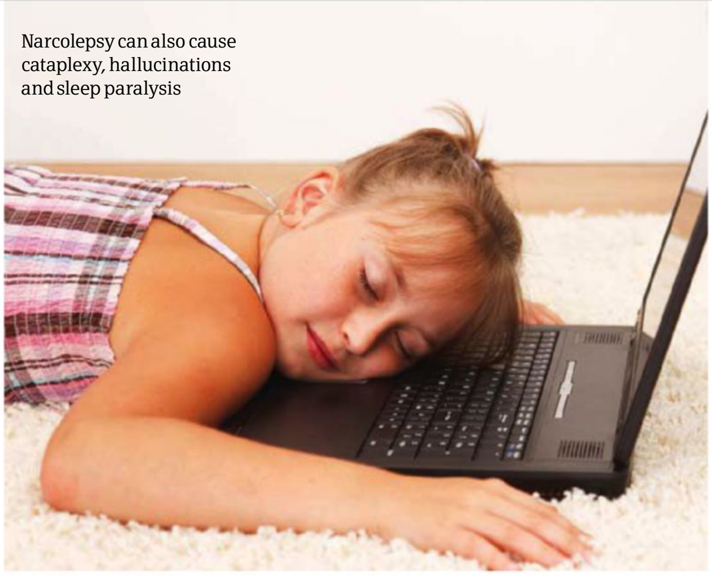




TYPES OF FRICTION

THE CHARACTERISTICS AND EFFECTS OF FRICTION VARY DEPENDING ON CONTEXT

1. **Static friction** The resisting force between two solid, static surfaces of contact.
2. **Kinetic friction** The resisting force between two solid, moving surfaces of contact.
3. **Fluid friction** The type of friction experienced between two surfaces within a viscous fluid, when moving relative to each other.
4. **Skin friction** The force resisting the motion of a solid object within a fluid (also known as drag).
5. **Internal friction** The force resisting motion between components of a solid material while being deformed.

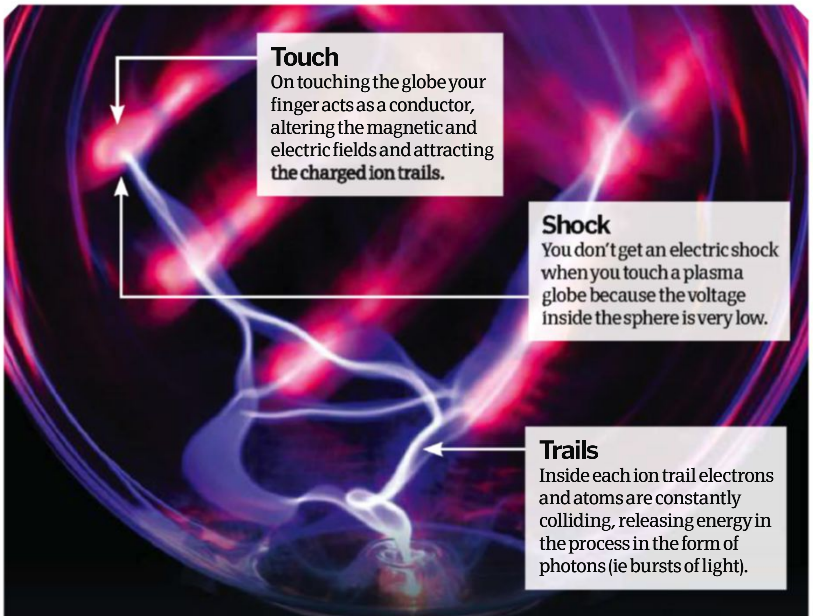

Narcolepsy can also cause cataplexy, hallucinations and sleep paralysis

Narcolepsy explained

What causes those with this condition to suddenly drop off?

Narcolepsy is a sleep disorder caused by a malfunction of the nervous system. It is widely considered to be the result of a deficiency of hypocretin, a chemical in the brain that activates arousal and regulates sleep. Why the deficiency occurs is unknown, but scientists are working on ways of supplementing hypocretin to reduce symptoms.

Narcolepsy is often inherited and symptoms include periods of extreme drowsiness every three to four hours, often resulting in a short nap. Most episodes last just 15 minutes, then they awake refreshed, but periods of sleep can last longer. It's common for those afflicted to fall asleep after meals but it can also happen while driving, talking or at work. Sufferers may hallucinate at the stage between sleep and wakefulness, or experience sleep paralysis, where they are unable to move immediately before or after sleep. Further, during wakefulness, some people experience a sudden loss of muscle tone, called cataplexy.



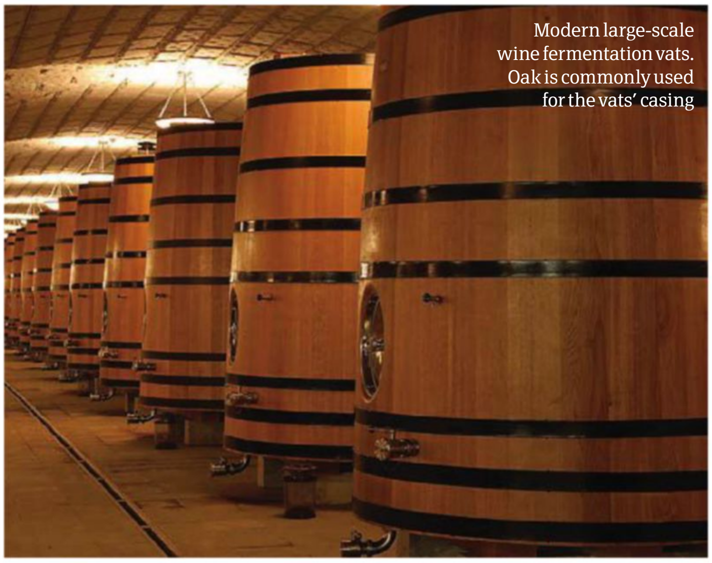
Plasma globes

How do these mesmerising balls of light work?

First invented by Nikola Tesla, the plasma globe has been a popular gadget for many years. The globe, made of glass, is filled with an inert gas such as neon and at its centre is a metal electrode. When a voltage is applied to the electrode (usually through mains electricity or a battery), the electricity jumps between the metal electrode and the outer glass wall, creating an electric field between the two.

The gas inside the globe makes this transition easier and visible. When the electrons have the required amount of energy to jump between the electrode and the glass, they continue to accelerate and gain more than enough energy to ionise the gas.

By doing this they create an ion trail, which other electrons subsequently travel upon. Collisions within the trails between atoms and electrons give off energy in the form of light. The colour of the trails will depend on the type of gas being used in the globe, with gases such as neon and helium giving red and white colours, respectively.


Modern large-scale wine fermentation vats. Oak is commonly used for the vats' casing

Making wine

From grape to plonk, a step-by-step overview of the science of wine

Mass-market wine-making, also known as viniculture, comprises several major steps.

First, after harvesting, grapes are squashed by a crushing unit, which either maintains or removes the stem and skin depending on the type of wine that is being produced.

Once crushed, the grapes are deposited into a fermentation unit, where primary alcoholic fermentation takes place. Yeast is already present in the grapes to initiate this process, but due to natural yeast generating unpredictable results, cultured yeasts are added too.

Next, the fermentation units undertake temperature-controlled stabilisation, dropping the mixture close to zero degrees Celsius (32 degrees Fahrenheit) to reduce and separate the buildup of tartrate crystals (sediment).

At this point, the wine mix is sent for secondary malolactic fermentation, a process that takes between three and six months. Here proteins within the liquid are broken down and any remaining yeast cells and fine particles dissipate. Finally, preservatives are added to the wine, while blending and 'fining' are done pre-bottling.

How do gastric bands work?

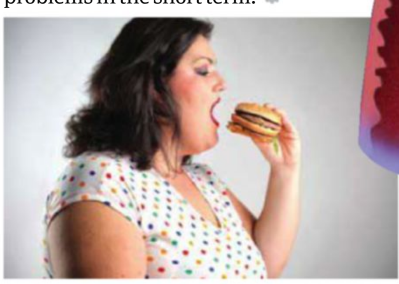
Gastric bands aren't just for cosmetic purposes – they can help to prevent health problems too

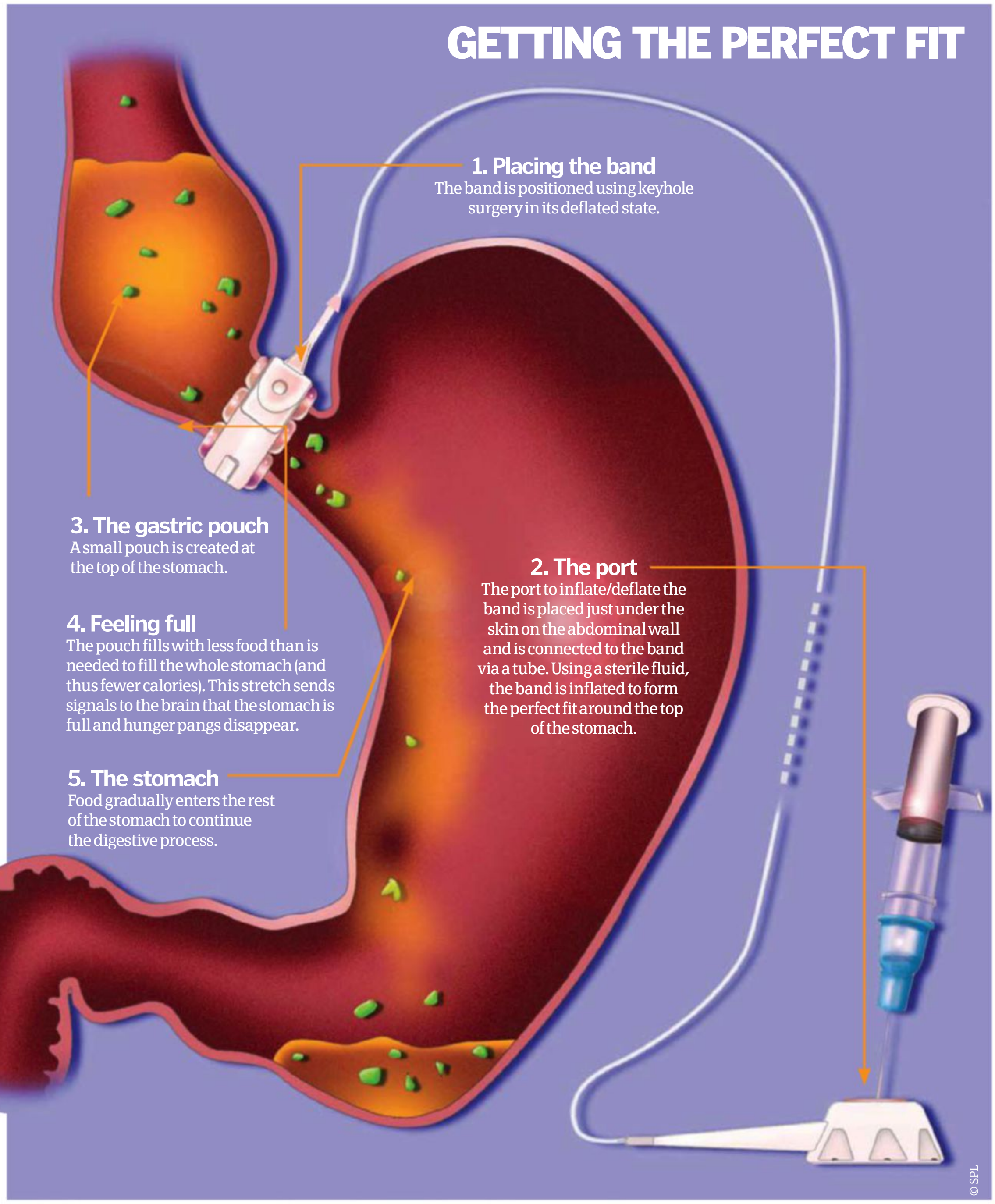
Gastric bands are inflatable circular balloons that are placed around the top of the stomach. They reduce the total capacity of the sack-like organ, so when the patient eats, their stomach wall stretches sooner and tells their brain that they are full, but with a smaller volume of food. This leads to a lower daily calorific intake and, as part of a controlled diet and exercise regime, results in weight loss.

The band is typically placed with keyhole (or laparoscopic) surgery, leading to smaller scars, less pain and a shorter hospital stay. However, patients first need a vigorous workout. They must try and lose weight through conventional methods and medications, which may take up to six months. All patients undergoing weight-loss surgery must see a health psychologist too. The patients should be mentally prepared and positive that a gastric band will help them slim down as part of a holistic approach – for example, it won't work if they continue to eat pizza and chips at every meal!

The band is placed in position in its deflated state. Through a port placed just under the skin, its size can be adjusted incrementally, leading to a controlled rate of weight loss; uncontrolled, over-quick weight loss can be very dangerous.

As with any medical procedure, there are potential risks and complications. The band can slip or become too tight, leading to pain and visits to the emergency department. In these circumstances, deflating the band through the port beneath the skin solves most problems in the short term.





5 TOP FACTS GASTRIC BANDS

History
1 The first non-adjustable band, made of a permanent mesh, was used in the Seventies. It wasn't until the early-Nineties, with the arrival of keyhole surgery, that adjustable bands became common.

At any rate...
2 Most experts agree that weight loss of approximately 1kg (2.2lb) a week is safe – any faster than this and you can risk dangerous metabolic side-effects.

Extra treatment
3 Although gastric bands are successful in most patients, in some they will have no effect. Around a third of patients will need a further procedure related to the band.

Be a patient patient
4 Gastric band surgery doesn't work immediately and can take up to 12 months to take effect; this is in contrast to a sleeve gastrectomy or bypass operation, which work immediately but are more invasive.

Up in the air
5 Most surgeons recommend deflating the band by half before flying. If it's full, any trapped air bubbles can expand and cause painful excessive restriction.

DID YOU KNOW? *The first adjustable gastric band was patented by Dr Dag Hallberg in Sweden in 1985*

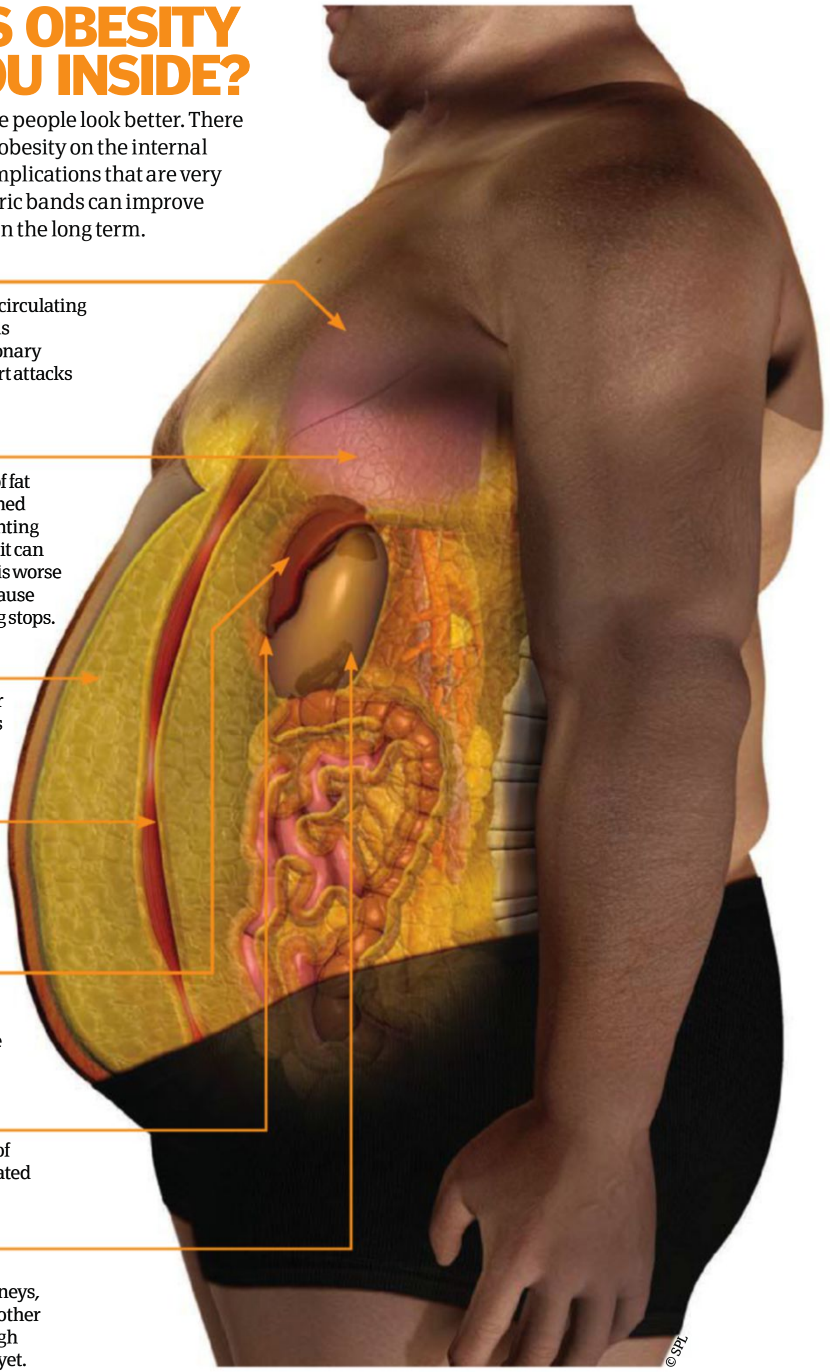
How healthy are you?

The body mass index (BMI) is commonly used to estimate a person's body fat. It is utilised around the globe, including by the World Health Organisation. It estimates a person's body size by dividing their weight by their height squared (ie BMI = weight in kilograms/ height in metres squared). The advantages are that it is easy to use, is the same for males and females and, in adults, is age independent. In children, it is used slightly differently and correct values vary according to age.

The BMI reading corresponds to categories of underweight, normal, overweight and obese. The disadvantage of the BMI system is that it doesn't take into account people's differing body proportions or muscle bulk. Athletes with lots of muscle, for example, would be classified as being overweight and thus unhealthy, although they're probably very fit. Some children who grow at different rates may be classed as outside normal ranges too, whereas they are in fact just in a growth spurt. That's why BMI must be used in conjunction with the person's overall fitness and appearance, and should be measured at several points over time to detect trends.

HOW DOES OBESITY AFFECT YOU INSIDE?

Gastric bands don't just make people look better. There are serious consequences of obesity on the internal organs, which have health implications that are very expensive to treat. Thus gastric bands can improve health and be cost-effective in the long term.



The heart
Obesity reflects underlying high-circulating triglycerides and poor health. This 'circulating fat' can block the coronary arteries, leading to angina or heart attacks (myocardial infarctions).

The lungs
When obese people have a layer of fat sitting on their chest wall, combined with fat from the abdomen preventing complete expansion of the lungs, it can lead to breathing problems. This is worse at night when lying flat and can cause sleep apnoea, where all breathing stops.

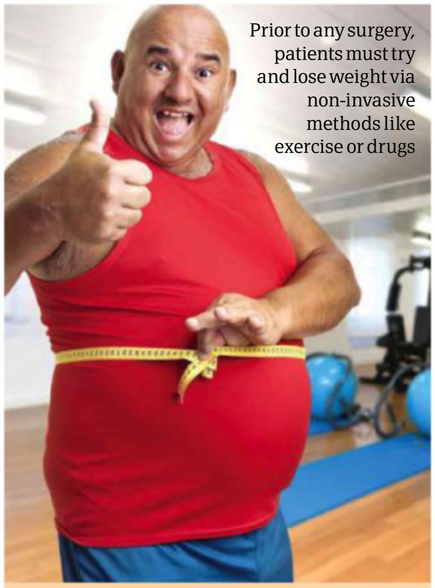
The abdominal wall
Everyone has a fatty layer on their abdominal wall. In obesity, this is often larger and it reflects what's going on inside too.

The muscles
Everyone has rectus abdominis (six-pack) muscles, even if they're buried between layers of fatty adipose tissue.

The liver
Obesity can lead to fatty liver disease (FLD), which in turn can progress to serious scarring of the organ (known as cirrhosis).

The pancreas
Obese people are at a higher risk of developing diabetes, which is related to changes within the pancreas.

The kidneys
High levels of circulating fats can block the arteries feeding the kidneys, causing hypertension. There are other effects on the kidneys too, although these are not fully understood as yet.



Prior to any surgery, patients must try and lose weight via non-invasive methods like exercise or drugs

What's the alternative?

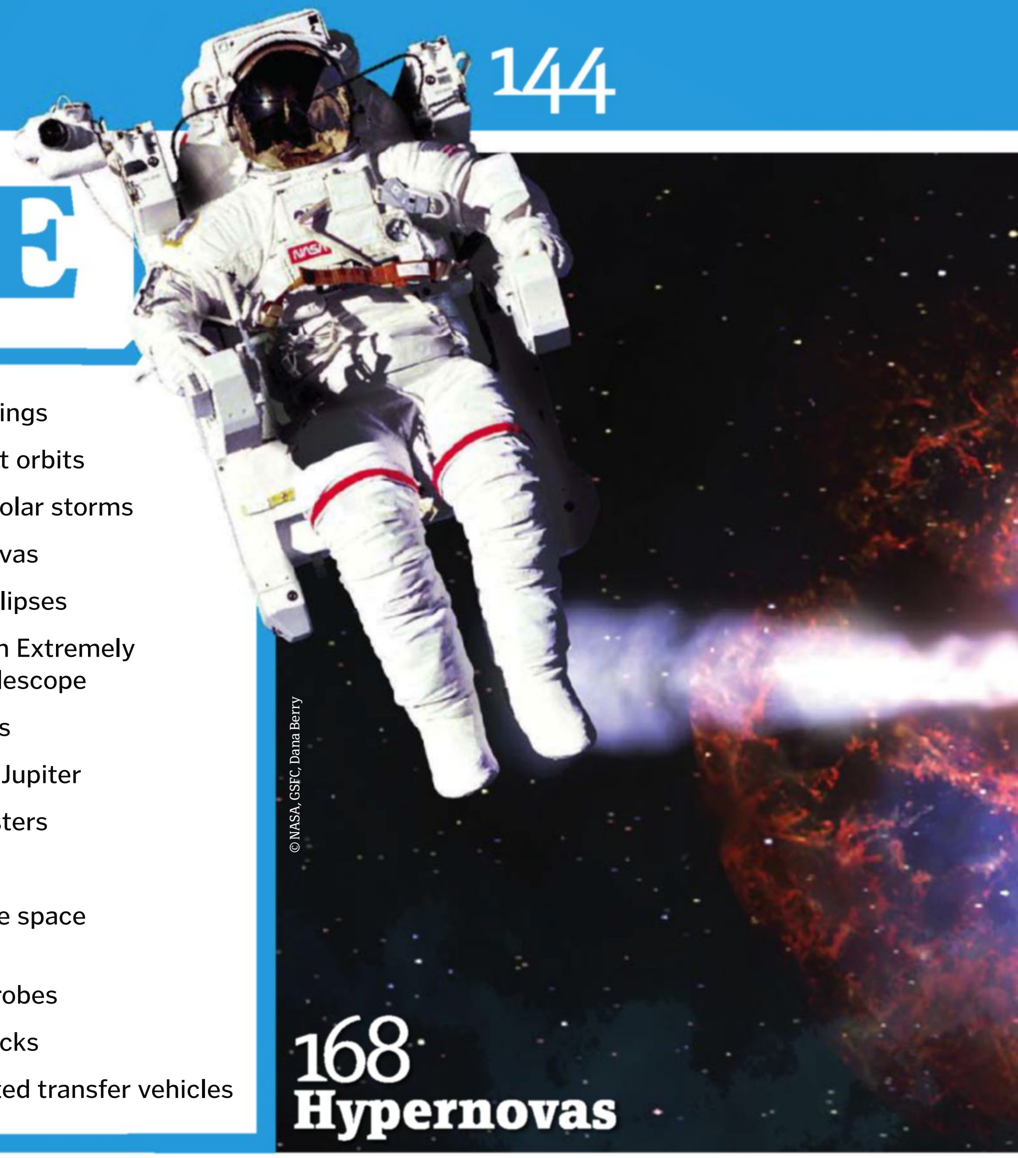
All patients should start with a regime of healthy eating and exercise before considering surgery. Medications should be tried next and, combined with the right lifestyle, most people will lose weight and regain their health. However, some people don't manage to lose weight, despite trying hard, so surgery is the only option left.

An alternative to the gastric band is the sleeve gastrectomy. During this procedure, most of the stomach is removed, leaving a sleeve-shaped tube. In a similar way to gastric bands, the patient feels full sooner, reducing the calorific intake. Gastric bands are not permanent and can be removed, but they can also slip out of place. Sleeve gastrectomies are permanent and won't dislodge, but the procedure is more invasive and there are other potential complications that will need to be discussed thoroughly with the surgeon.

During a gastric bypass, on the other hand, a small pouch of the stomach is created which is connected to the small intestine lower down. This has a malabsorption effect, which ultimately means that fewer calories from what is ingested are taken into the body.

There are other forms of intervention, such as intragastric balloons, but not enough evidence exists to assess them properly. Finally, abdominoplasty (a 'tummy tuck') is a quick way to get rid of some excess abdominal fat without changing anything inside; this is purely cosmetic surgery though and has no internal health benefits.

SPACE



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168 Hypernovas

© NASA, GSFC, Dana Berry

Inflatable space stations

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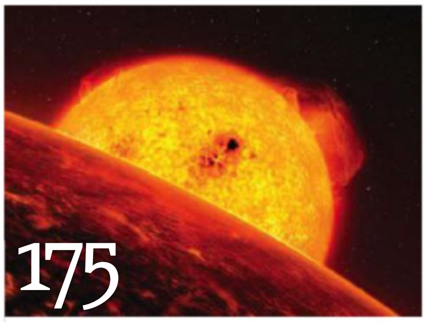

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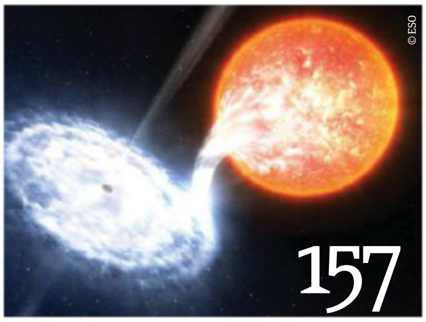

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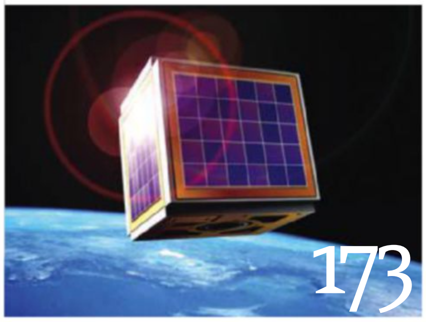

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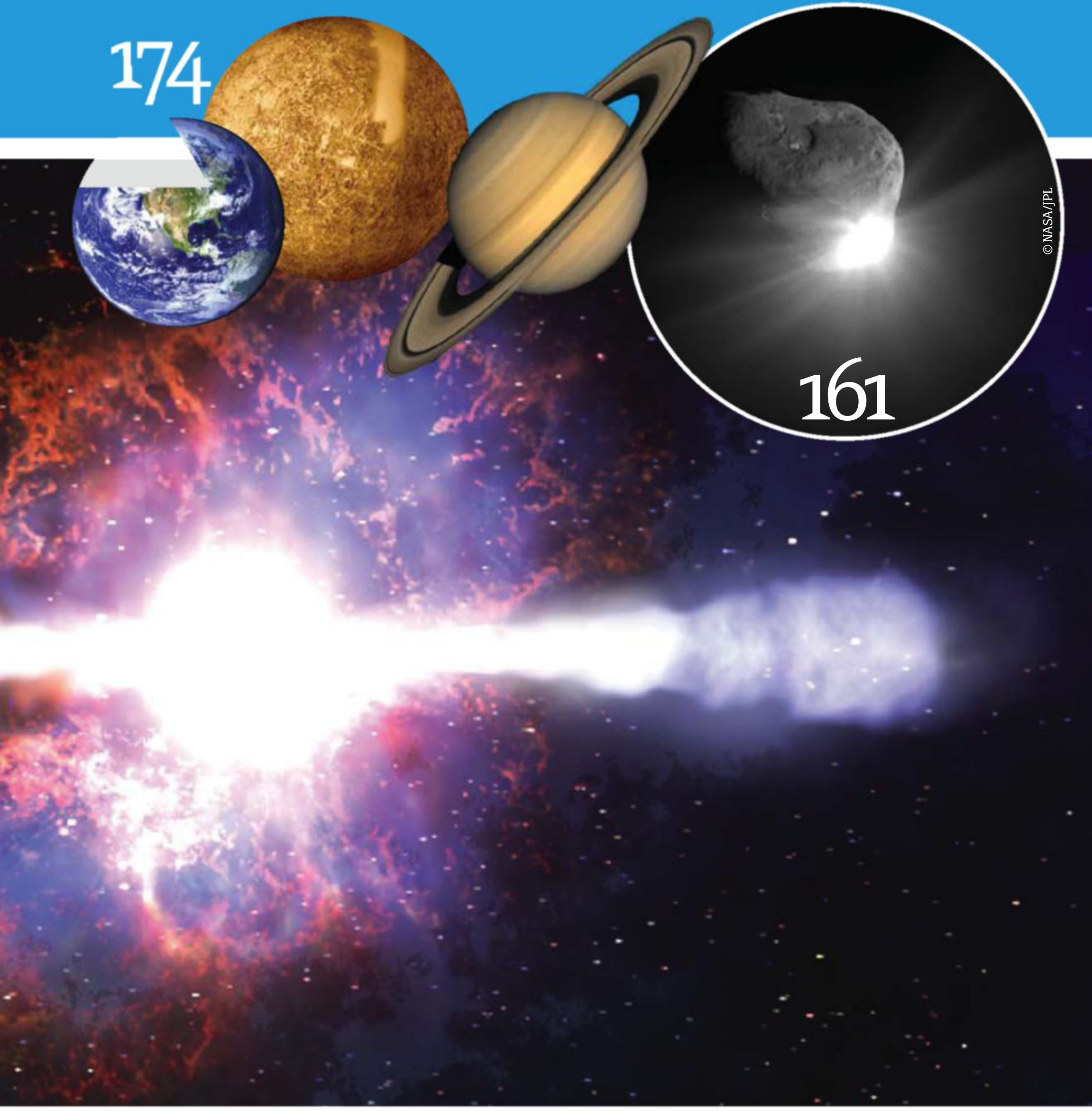


SURVIVE THE COSMOS

LIFE IN SPACE

Humans have had a presence in space in some form or another for half a century, but learning to live in the cosmos has been a steep learning curve. We take a look at what it's like to live in space, and how we've adapted over the years

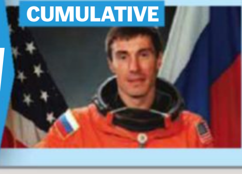
Living in space is the ultimate mental and physical test of the human body. On Earth, the experience of being in space is almost impossible to replicate; the closest astronauts can get is to train underwater but the experience is a world away from that first journey into orbit or beyond. There's no 'up' nor 'down' in space, so many sensory receptors are rendered useless while materials like water behave differently to how they do on Earth. So, how do astronauts cope, and what's it like to live in space?

Since Yuri Gagarin became the first man to leave the Earth in 1961, life in space has altered and improved dramatically. Gagarin spent the entirety of his 108-minute flight encased in a spacesuit, but nowadays astronauts can wear the same shorts and T-shirts they would wear at home. The first space station, Russia's Salyut (launched in 1971), saw astronauts eat food from freeze-dried packets and stay only briefly on the station in order to survive. Now, astronauts aboard the International Space Station (ISS) can eat pizza and curry, reuse and recycle many of their utilities and can stay in orbit for hundreds of days.

Before the ISS there were many unknowns about living in space. Indeed, on the earlier space stations Mir and Skylab, procedures and equipment were much less advanced than they are now. For one thing, it was quickly realised that astronauts must sleep close to a ventilation fan. If they don't they run the risk of suffocation. The reason for this is that, as they sleep, warm air does not rise in a weightless environment. Therefore, in a badly ventilated area they would be surrounded by a bubble of their own exhaled carbon dioxide. A regular supply of air (oxygen) is needed to allow for regulated breathing.

Over the years sleeping methods have changed, from slumbering in a sleeping bag attached to a wall, on NASA's Space Shuttle, for example, to having their

CUMULATIVE



1. 803 days
A Russian cosmonaut called Sergei Krikalev, 53, has spent a total of 803 days, 9 hours and 39 minutes in space across six missions.

CONTINUOUS

2. 437 days
The record of longest single spaceflight in history is currently held by Russian Valeri Polyakov, 69, who spent 437 days and 18 hours aboard the Mir space station.

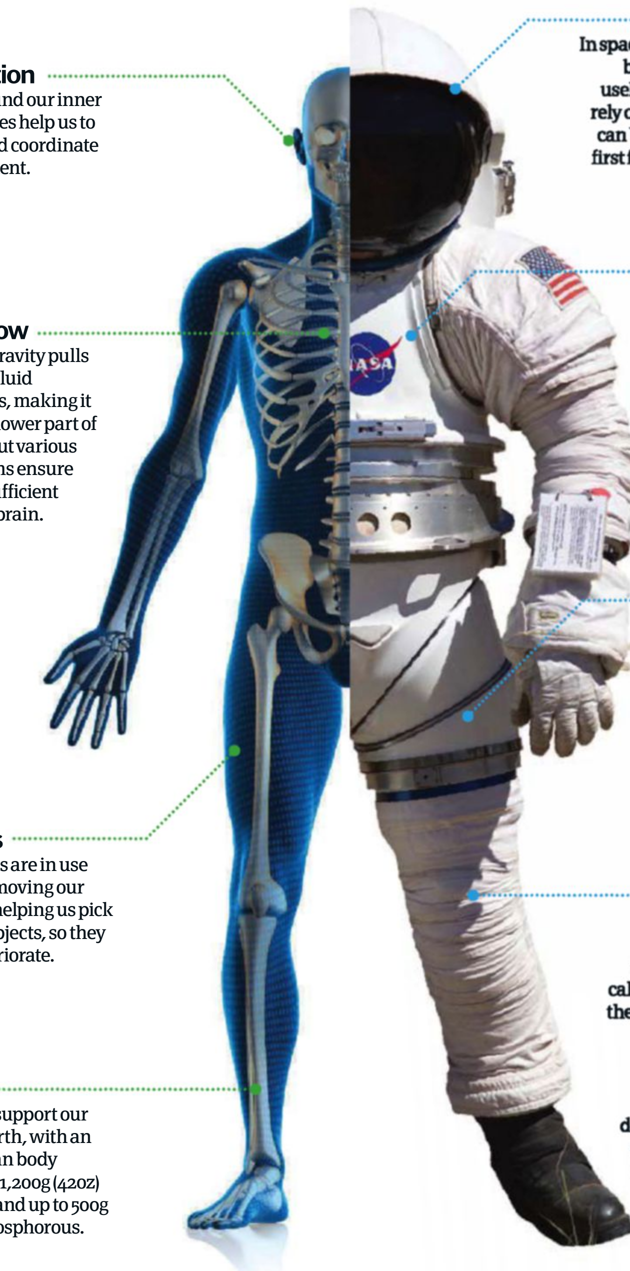
CANINE

3. 22 days
Veterok and Ugolyok jointly hold the record of longest canine spaceflight, spending 22 days in orbit in 1966 before returning to Earth.

DID YOU KNOW? *You grow taller in space because your spine elongates – some reports suggest by an inch in just ten days*

Space bodies

How does living in space affect the human body?



EARTH
Orientation
On the ground our inner ears and eyes help us to balance and coordinate our movement.

SPACE
Orientation
In space the balance provided by the inner ear is all but useless, so astronauts must rely on visual receptors. This can be disconcerting for the first few days, and can result in space sickness.

EARTH
Blood flow
On Earth, gravity pulls our bodily fluid downwards, making it pool in the lower part of our body, but various mechanisms ensure there is a sufficient flow to the brain.

SPACE
Blood flow
In space bodily fluids are free of the effects of gravity, known as 'fluid shift'. They travel more easily to all parts of the body, often resulting in a stuffy nose and puffy face.

EARTH
Muscles
Our muscles are in use every day, moving our limbs and helping us pick up heavy objects, so they do not deteriorate.

SPACE
Muscles
In weightlessness an astronaut will have less need for their muscles as they can move themselves and heavy objects easily. Muscles will quickly weaken without regular exercise.

EARTH
Bones
Our bones support our body on Earth, with an adult human body containing 1,200g (42oz) of calcium and up to 500g (18oz) of phosphorous.

SPACE
Bones
In a zero-gravity environment, phosphorous and bone calcium are removed from the body during excretion. After ten days of weightlessness, 3.2 per cent of each bone's calcium is lost. This decrease in bone density can lead to fractures, so exercise must be taken regularly to maintain their strength.

own small compartment on the ISS. Sleeping isn't easy, either. Astronauts experience a sunrise and sunset every 90 minutes as they fly at 27,360km/h (17,000mph) around the Earth, so clocks on the ISS are set to GMT and astronauts live their days just as they would on Earth. They work for over eight hours on weekdays, but on weekends they are given much more leisure time, although work must still be done to keep the ISS safe and operational, in addition to checking on experiments. Life in space isn't tough just for humans; animals have struggled as well. On NASA's Skylab space station in the Seventies, spiders were taken up to see how they would cope in a weightless environment. While disorientated they still managed to spin a web, even if it was a little wonky. More famous was the first living animal to be sent into space from Earth, Laika the dog from Russia. Sadly, she perished in orbit, but she was said to cope well with the experience of weightlessness. At the very least, Laika proved that animals could survive in space, providing the basis for Gagarin's later mission and all future human missions into the cosmos.

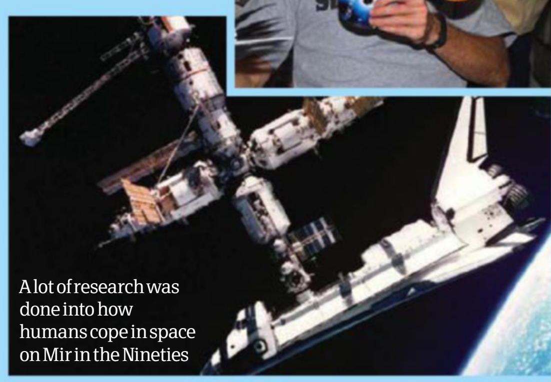
Astronauts often call friends and family at home by video or audio phone to overcome feelings of loneliness

Space psychology

How astronauts cope with the mental strains of space

Over the years psychologists have devised new ways to keep astronauts on target and mentally sound. The first major opportunity to test a human's capability to withstand the mental strains of space was Russia's Mir space station in the Nineties. Russian psychologists used the 90,000 flying hours of data available to learn about the psychology of long-term space flight. They discovered that astronauts tend to go through a three-stage process. The first saw an acclimatisation to their environment, where the initial thrill of being in space was enough to make them forget, or at least think less, about home. However, after about two months the astronauts entered a second phase, where signs of mental fatigue began to appear, while morale and motivation were low. Today, astronauts are given as much free time as possible and allowed to occupy themselves outside work hours with activities like playing the guitar, watching DVDs or talking to friends and relatives by phone or email. The final stage was one of hypersensitivity, irritability and nervousness, which the Russians called 'asthenia'. This is less prevalent today thanks to the aforementioned forms of entertainment.

Entertainment, such as watching DVDs, provides astronauts with some relief from the strains of living in space



A lot of research was done into how humans cope in space on Mir in the Nineties

Each human consumes 0.9kg (2lbs) of oxygen daily, which is enough to fill a 3.5 cubic metre (123.6 cubic feet) room, and drinks 2.7kg (6lbs) of water. Therefore, the life-support systems on board the ISS recycle as much waste as possible, including that from urine and condensed moisture in the air, both of which are purified and reused, often after being broken down by electrolysis to provide fresh oxygen. However, not all water can be reused, and thus astronauts must rely on regular re-supply vehicles to bring cargo to the station. These have been performed by several spacecraft over the years, such as NASA's Space Shuttle until its retirement in July 2011, but they are now largely carried out by the ESA's Automated Transfer Vehicle (ATV). The ATV brings fresh food, clothes, water and equipment to the station. Once the cargo has been delivered, astronauts fill the vehicle with 5,896kg (12,998lbs) of waste and it is sent to burn up in Earth's atmosphere.

These are just some of the many ways that astronauts have adapted to life in space, and as more and more time is spent on the International Space Station, our capabilities to perform in a weightless environment will no doubt improve. The ultimate goal of sending humans to an asteroid and Mars in the 2030s is looking like an increasingly achievable objective thanks to the tireless work of space agencies worldwide over the last 50 years.

> "Nowadays astronauts can wear the shorts and T-shirts they would wear at home"

The ESA-built Cupola is a popular module where astronauts can get a fantastic view of Earth

A DAY IN SPACE

Astronauts aboard the ISS experience 15 'dawns' every day, but while they're on board the station they operate according to GMT so they can stay in direct contact with the ground at operational hours. Here's how a typical day pans out for an astronaut on the station

08:00 Daily conference/work

In the morning astronauts perform the first of their daily tasks assigned by ground control. They often have a daily conference where they discuss their jobs for the day. Their work consists of supervising experiments that would not be possible on Earth or performing routine maintenance on equipment to ensure the survival of the crew. On some days they take video calls from Earth. These are often simply to friends and family but, on rare occasions, they may talk to schoolchildren, the US president or even the Pope.

06:40 Breakfast/getting ready

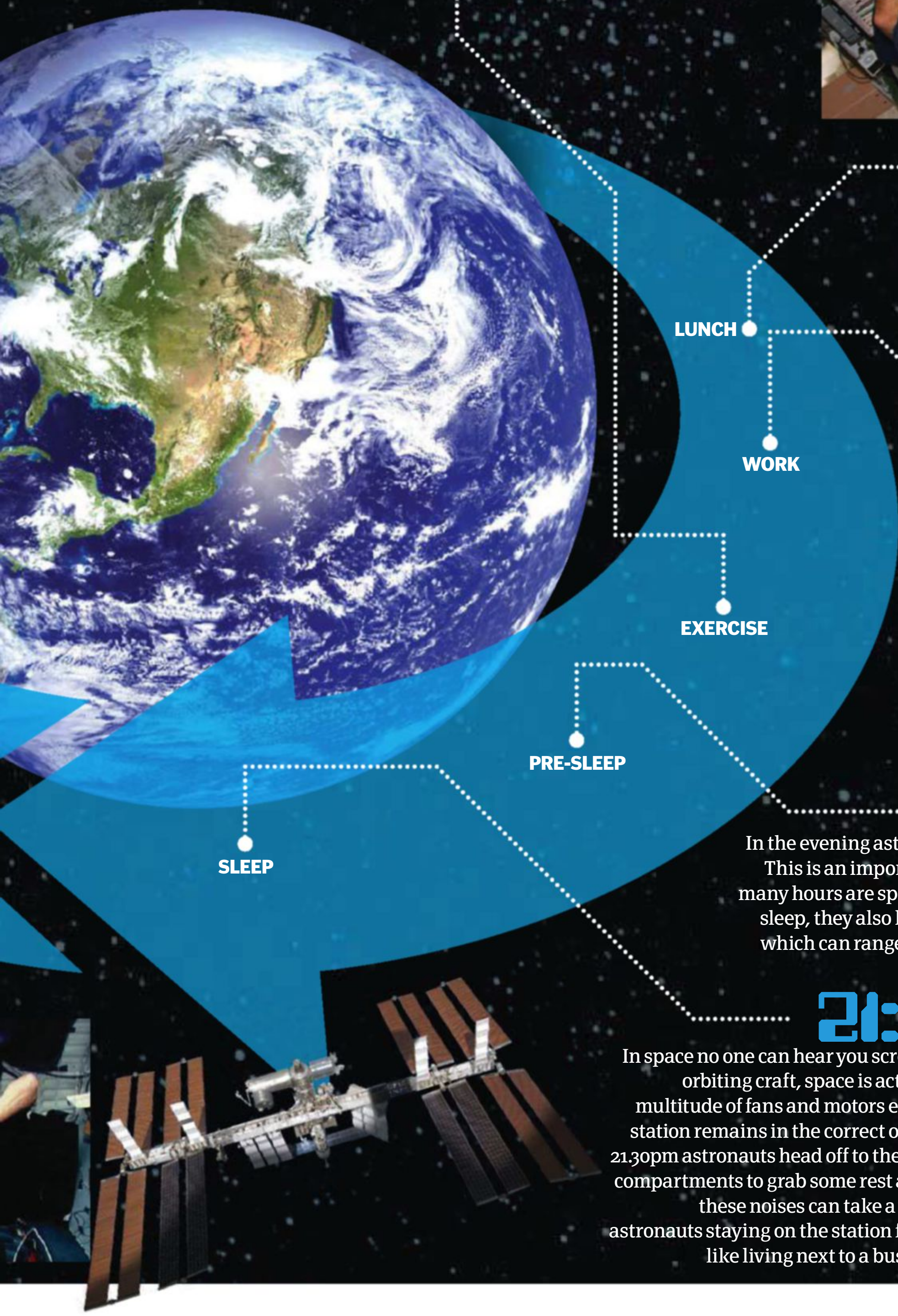
Astronauts eat their first meal of the day, which is nothing like the freeze-dried food of the Apollo missions. Fresh fruit and produce are stored on the ISS, while tea and coffee are available in packets. Astronauts can wear anything from shorts and T-shirts to trousers and rugby shirts. Astronauts cannot wash their clothes on the ISS because water is limited, so they tend to re-use their shirts, socks and trousers. Most have just a few shirts and socks for their six-month-long stay on the ISS, but because the station is so clean they pick up very little dirt and thus remain hygienic.

06:00 Post-sleep

Astronauts are woken up at 6am. On the ISS most astronauts have their own sleeping compartments, small telephone booth-sized spaces where the astronaut can lie vertically (although this doesn't matter as there is no 'up' or 'down' on the station). After waking they will get washed and dressed before eating breakfast, much like a regular day on Earth. However, there is no shower on the ISS. Instead, astronauts wash their bodies with water-squirting guns and specially designed towels that are impregnated with soapy liquid. Grooming techniques such as shaving are difficult on the ISS, as surface tension makes water and shaving cream stick to an astronaut's skin and the razor blade in globules.

10:00 & 17:00 Physical exercise

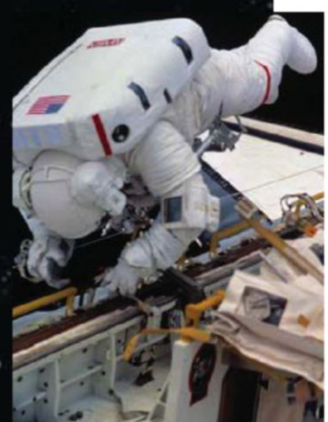
Astronauts must exercise regularly, at least two hours a day, to keep their body in optimum condition while in space. Bones and organs can become frail and weak in a weightless environment. Therefore astronauts on the ISS have a variety of exercise equipment, like treadmills and cycling machines, to keep them strong.



13:00 Lunch

Prolonged microgravity dulls tastebuds, and the white noise doesn't help (like being on an aircraft), so foods with strong flavours (such as spicy curries) are often the preferred choice for meals.

14:00 Back to work



On rare occasions astronauts will have to leave the station on an extra-vehicular activity (EVA). For this astronauts will don a spacesuit and perform work outside the ISS. Before they leave they must exercise for several hours in a decompression chamber to prevent suffering from the 'bends' on entering space. Work outside the station ranges from maintenance to installing or upgrading components.

19:30 Pre-sleep

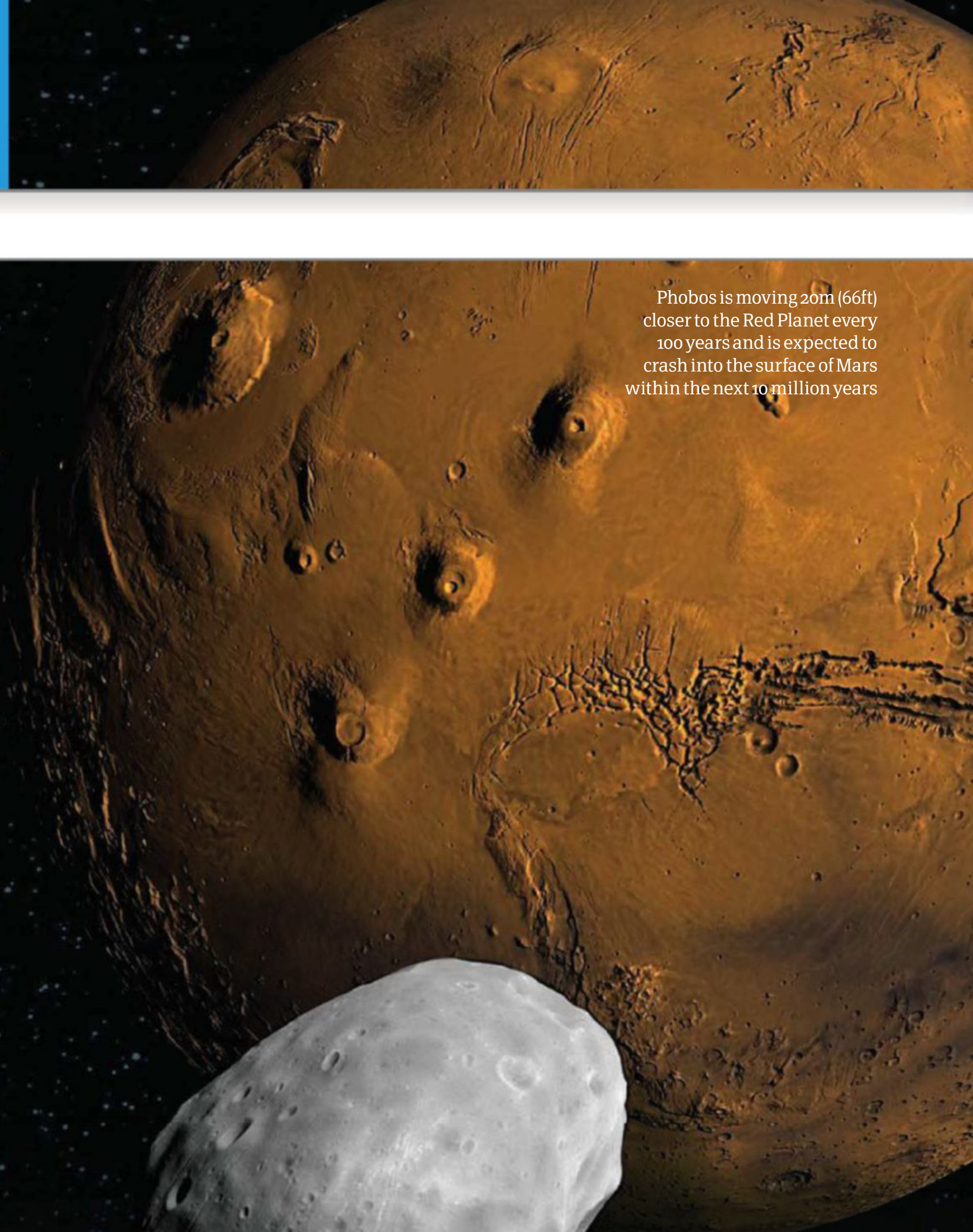
In the evening astronauts eat dinner in a communal area. This is an important time for social interaction, as often many hours are spent working alone on the station. Before sleep, they also have a chance for a bit of entertainment, which can range from watching a DVD to playing guitar.

21:30 Sleep

In space no one can hear you scream, right? Well, in an orbiting craft, space is actually very loud, with a multitude of fans and motors ensuring that the space station remains in the correct operational capacity. At 21.30pm astronauts head off to their designated sleeping compartments to grab some rest and, while reassuring, these noises can take a while to get used to for astronauts staying on the station for the first time, much like living next to a busy main road on Earth.

Phobos

Explore the unusual surface of this doomed Martian moon



Phobos is moving 20m (66ft) closer to the Red Planet every 100 years and is expected to crash into the surface of Mars within the next 10 million years

The larger of Mars's two moons (the other being Deimos), Phobos is not circular in appearance like most other moons in the solar system. At its largest extreme it is 26 kilometres (16 miles) across, but only 18 kilometres (11 miles) across at its shortest.

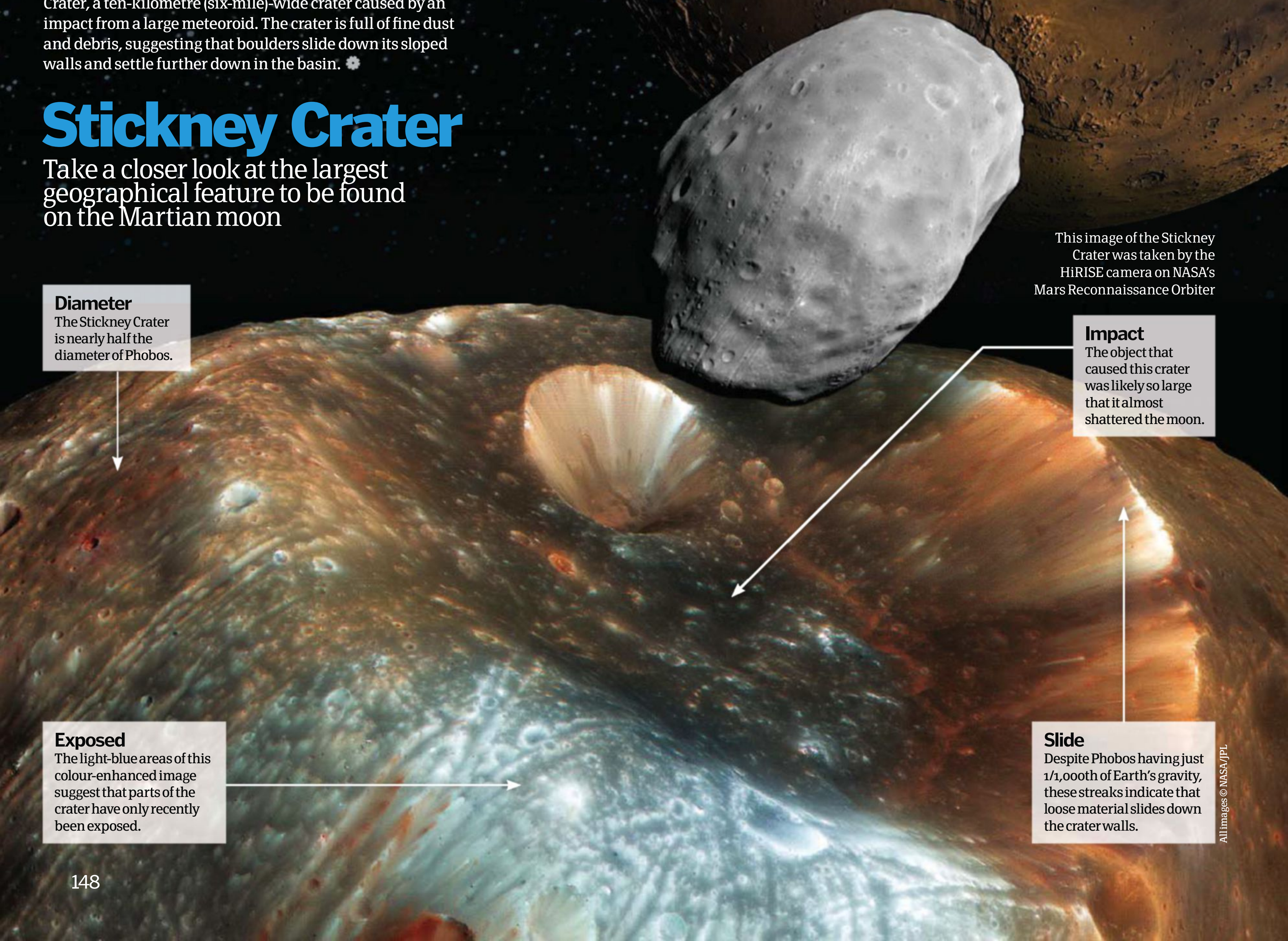
Eons of meteoroid impacts have given Phobos a rather battered appearance, with dark trails resulting from landslides marking the steep slopes of the large craters on its surface, in addition to a host of smaller craters.

The moon is tidally locked to Mars, and its close proximity to the Red Planet – an average distance of 9,378 kilometres (5,828 miles) above its surface – means that half of the moon has a temperature of -4°C (25°F), while in contrast, the far outward-facing side can drop as low as -112°C (-170°F).

The largest feature on this Martian moon is the Stickney Crater, a ten-kilometre (six-mile)-wide crater caused by an impact from a large meteoroid. The crater is full of fine dust and debris, suggesting that boulders slide down its sloped walls and settle further down in the basin.

Stickney Crater

Take a closer look at the largest geographical feature to be found on the Martian moon



This image of the Stickney Crater was taken by the HiRISE camera on NASA's Mars Reconnaissance Orbiter

DID YOU KNOW?

Solar necessity

One of the reasons for using solar power on board Juno is that NASA has almost depleted the USA's stock of plutonium-238, a radioactive isotope often used to power spacecraft. Attempts to gain funding for further production have repeatedly failed.

DID YOU KNOW? Juno and New Horizons are part of NASA's New Frontiers Program to explore our solar system

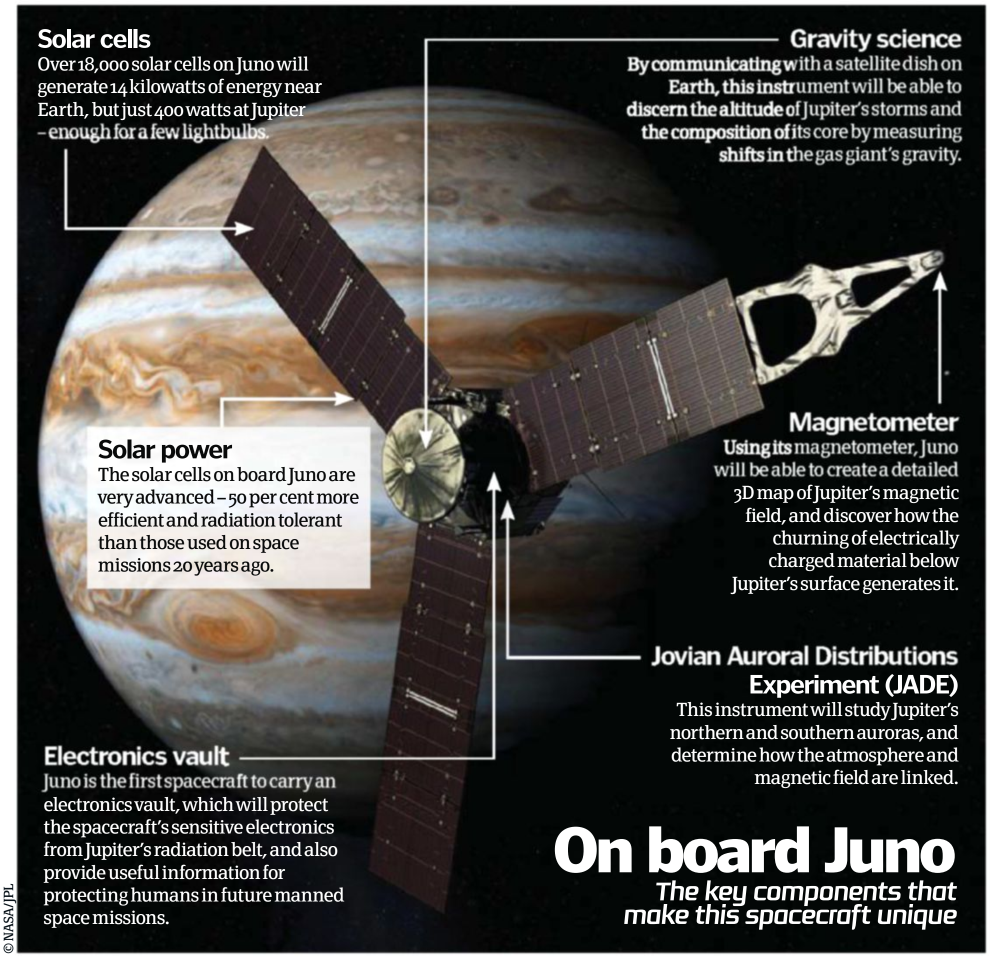
Juno spacecraft

We take a look at this revolutionary spacecraft on its way to Jupiter

NASA's Juno spacecraft launched on 5 August 2011 atop an Atlas V rocket, beginning its five-year journey to Jupiter, where it will study key features of the giant planet. Juno contains revolutionary technology, and will also complete some intricate manoeuvres throughout its mission.

Just after it launched, rocket motors from the second-stage rocket booster started Juno spinning at a rate of three rotations per minute. This enables it to remain stable and easy to control, in addition to providing its instruments with a sweeping view of the entirety of Jupiter 400 times every two hours once it arrives. This is the time it will take to orbit between Jupiter's poles, which Juno will do 32 times during its one-year scientific observations of the planet. At the end of its mission, Juno will be sent crashing into the gas giant to prevent it from contaminating one of the nearby moons that could harbour life.

Juno will become the first NASA spacecraft to operate at this distance on solar power alone. Jupiter orbits the Sun at a distance five times further than the Earth, and thus receives 25 times less sunlight. For this reason, the solar panels of Juno are very large to generate enough power for the instruments to function, each nearly 10 metres (30 feet) long and 2.7 metres (nine feet) wide. The mission is designed so that after a flyby of Earth, Juno will always be in sunlight, with its Jupiter orbit designed to avoid being out of view of the Sun. Thanks to its modest power needs, Juno's instruments each needs just six hours of full power every 11-day orbit to perform the required observations.



Ice haloes are fairly common in cold climates

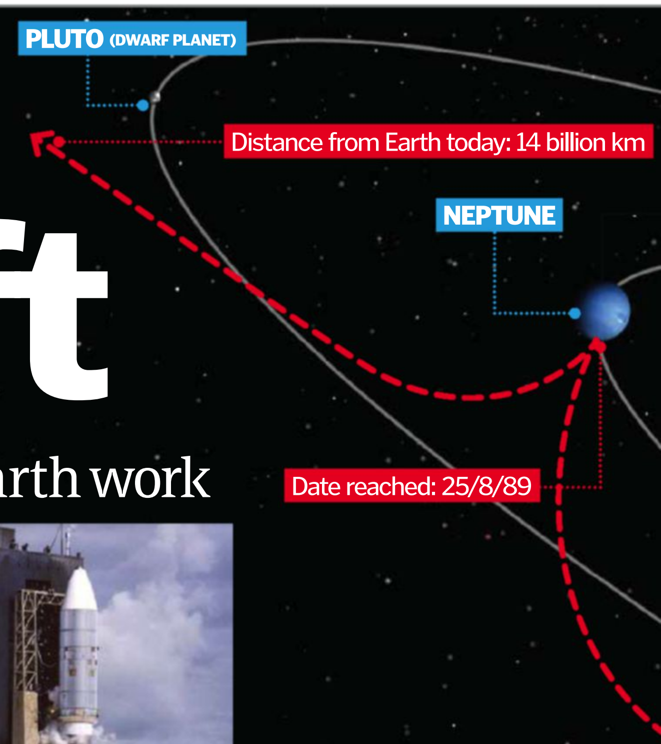
Ice haloes

How do these rings of light form?

Ice haloes are a fairly common sight in cold climates, where the Sun or moon appears to be surrounded by a ring of light. The haloes are caused by millions of tiny ice crystals contained in high, thin clouds in the troposphere. Each crystal acts like a lens, and refracts (or bends) light from the Sun or moon at 22 degrees, which corresponds to the radius of the halo, subsequently causing the circular band of light to form.

Each ice crystal has the same hexagonal shape, so they refract the incoming light at the same rate, producing an almost perfect circle. However, the reason for the formation of ice crystals in some clouds but not others remains something of a mystery.

Voyager spacecraft



How the furthest man-made objects from Earth work

On 20 August 1977 Voyager 2 launched from Cape Canaveral in Florida aboard a Titan-Centaur rocket, heralding the start of one of the most ambitious deep space exploration missions of all time. Two weeks later Voyager 1 was sent up in an identical launch, although its greater speed meant that it eventually overtook Voyager 2. The list of accomplishments by the two probes is astounding. Between them they have studied all of the major planets of the solar system past Mars, in addition to some moons of Jupiter and Saturn, making countless new discoveries in the process. Now, as the furthest man-made objects from Earth, they are on their way out of the solar system.

The launch of the mission coincided with a favourable alignment of the planets in the Seventies that would allow Voyager 2 to visit Jupiter, Saturn, Uranus and Neptune. The list of achievements by the two Voyager spacecraft is extensive. The Voyager mission was only the second – after Pioneer 10 and 11 in 1974 and 1975, respectively – to visit Jupiter and then Saturn, but it also discovered the existence of rings around Jupiter, while Voyager 2 was the first mission to visit Uranus and Neptune.

The primary objective of the mission was to study Jupiter and Saturn, but once it became apparent that the spacecraft could continue working, the mission was extended to include Neptune and Uranus for Voyager 2. Voyager 1 could have travelled to Pluto, but NASA decided to extend its mission to Saturn and its moon Titan, leaving the dwarf planet Pluto one of the largest bodies in the solar system yet to be explored.

The Voyager probes obtain power from their radioactive generators, which have kept them running even at such a great distance from Earth and will continue to do so until about 2020, when they will no longer be able to power their instruments. Voyager 1 is roughly now over 17 billion kilometres (10.6 billion miles) from the Sun, while Voyager 2 is at a distance of over 14 billion kilometres (8.5 billion miles).

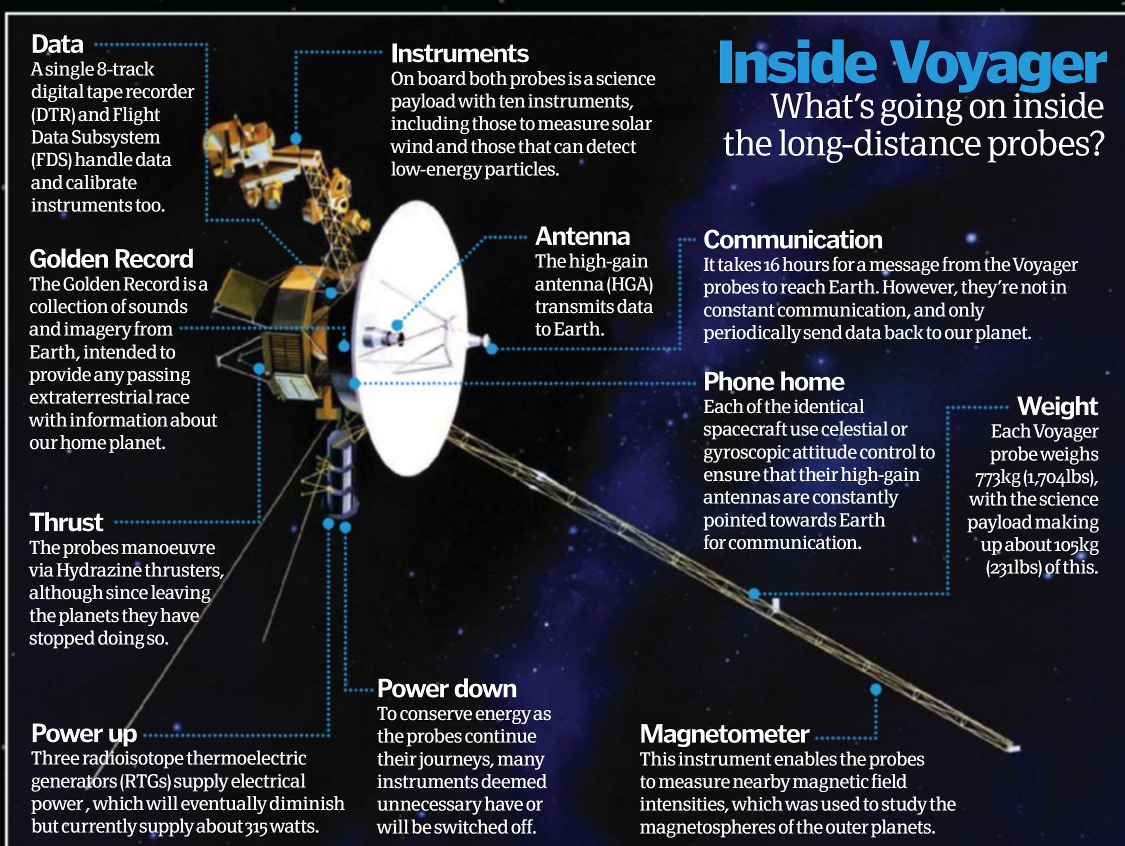
After making so many groundbreaking discoveries, both spacecraft are now on their way out of the solar system. They are both expected to pass out of the Sun's influence and into interstellar space in the coming years, although it is not entirely clear when this will happen as no machine has yet experienced the conditions that the Voyager probes are about to endure.

In 40,000 years, Voyager 1 should be within 1.6 light years (9.4 trillion miles) of a star in the constellation of Camelopardalis thought to harbour a planetary system. 256,000 years later, Voyager 2 will be 4.3 light years (25 trillion miles) from Sirius, which is the brightest star other than the Sun in our night sky.

Voyager 2 launched atop a Titan III-Centaur rocket on 20 August 1977

Inside Voyager

What's going on inside the long-distance probes?



Data
A single 8-track digital tape recorder (DTR) and Flight Data Subsystem (FDS) handle data and calibrate instruments too.

Instruments
On board both probes is a science payload with ten instruments, including those to measure solar wind and those that can detect low-energy particles.

Golden Record
The Golden Record is a collection of sounds and imagery from Earth, intended to provide any passing extraterrestrial race with information about our home planet.

Antenna
The high-gain antenna (HGA) transmits data to Earth.

Communication
It takes 16 hours for a message from the Voyager probes to reach Earth. However, they're not in constant communication, and only periodically send data back to our planet.

Phone home
Each of the identical spacecraft use celestial or gyroscopic attitude control to ensure that their high-gain antennas are constantly pointed towards Earth for communication.

Weight
Each Voyager probe weighs 773kg (1,704lbs), with the science payload making up about 105kg (231lbs) of this.

Thrust
The probes manoeuvre via Hydrazine thrusters, although since leaving the planets they have stopped doing so.

Power down
To conserve energy as the probes continue their journeys, many instruments deemed unnecessary have or will be switched off.

Power up
Three radioisotope thermoelectric generators (RTGs) supply electrical power, which will eventually diminish but currently supply about 315 watts.

Magnetometer
This instrument enables the probes to measure nearby magnetic field intensities, which was used to study the magnetospheres of the outer planets.

5 TOP FACTS VOYAGER DISCOVERIES

Moons
1 Around the outer planets the Voyager probes discovered 23 new moons, including five around Saturn and 11 around Uranus, in addition to imaging our own.

Interstellar medium
2 Both of the Voyager probes are now in a region where the Sun's influence is increasingly waning, and soon they will enter the interstellar medium.

Atmospheres
3 Voyager probes 1 and 2 both provided unprecedented information about the atmospheres of the following planets: Jupiter, Saturn, Uranus and Neptune.

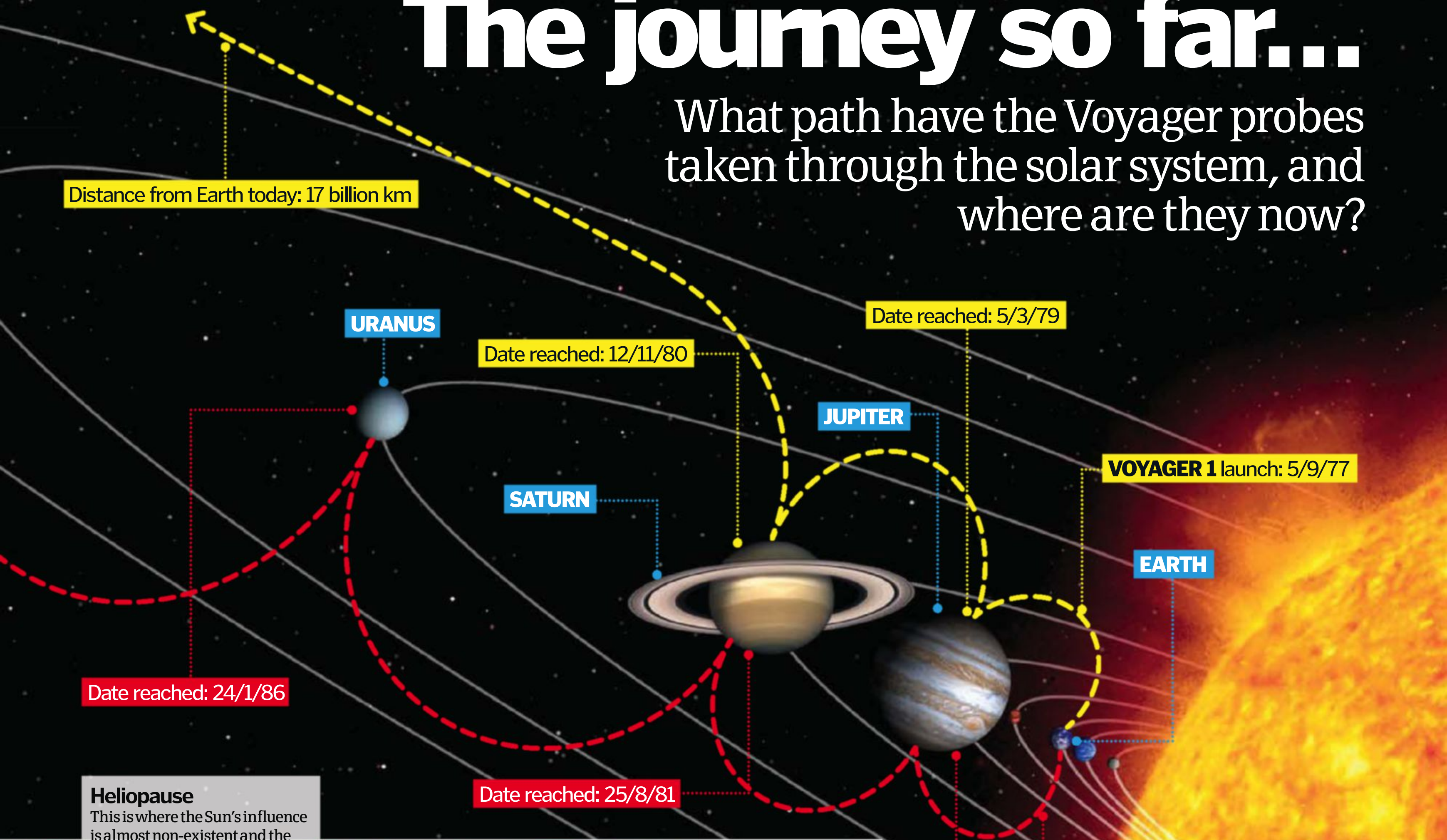
Jupiter
4 The probes discovered for the first time a ring system encircling Jupiter, and they also observed hurricane-like storms in the planet's atmosphere.

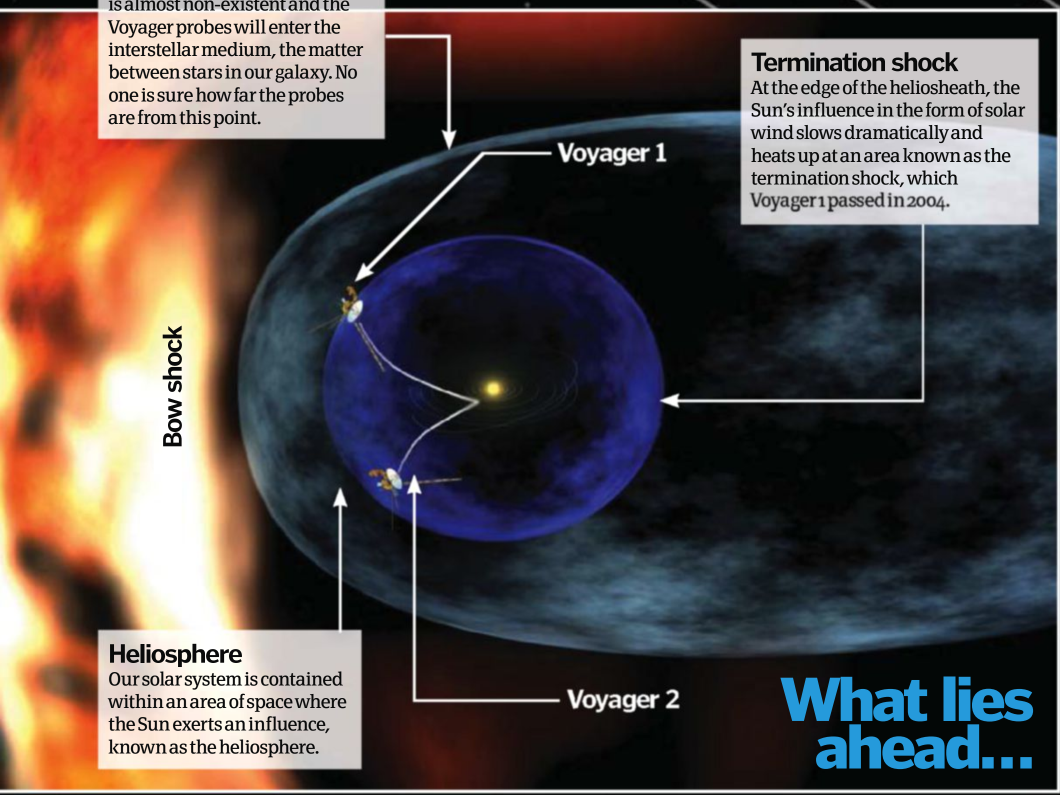
Io
5 Voyager 1 discovered the only known body in the solar system other than Earth to be volcanically active: Jupiter's moon Io. This moon also affects the surrounding Jovian system.

DID YOU KNOW? Voyager 1 is now travelling at 38,000mph, while Voyager 2 is slightly slower at 35,000mph

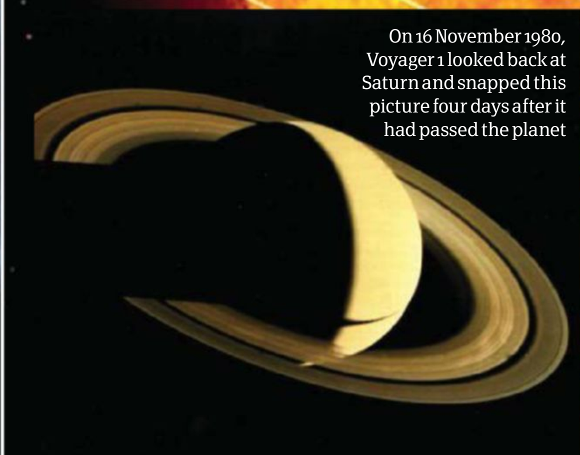
The journey so far...

What path have the Voyager probes taken through the solar system, and where are they now?





What lies ahead...



On 16 November 1980, Voyager 1 looked back at Saturn and snapped this picture four days after it had passed the planet

The Sombrero Galaxy

Named for its hat-like shape, what makes this galaxy so special?

Technically known as M104, the Sombrero Galaxy gets its odd appearance from an unusually large central bulge of stars that feature in a prominent dust lane also containing many globular clusters.

The Sombrero Galaxy was originally discovered by Pierre Méchain in 1781, and rediscovered independently by William Herschel in 1784. It later helped 20th Century astronomers deduce that the universe was expanding in all directions. Initially believed to be a young star surrounded by luminous gas, astronomer VM Slipher discovered in 1912 that M104 was actually a large galaxy moving away from Earth at 700 miles per second.

In the centre of this 50,000 light-years-wide galaxy resides a huge black hole that X-ray evidence suggests is a billion times the mass of our Sun. The large, glowing bulge around the centre of the galaxy is the result of the light from billions of old stars found throughout, while about 2,000 globular clusters between 10 and 13 billion years old surround the galaxy – ten times more than in our own Milky Way. Inside the dust lanes and rings surrounding the central bulge are younger, brighter stars.

The Sombrero Galaxy, about 29 million light years from Earth, lies southwards of the Virgo Cluster in the night sky. It is tilted edge-on to Earth at an inclination of about six degrees, is easily seen through small telescopes, and is almost visible with the naked eye.


The image was taken by NASA's Hubble Space Telescope

A CG rendering of a black hole firing out a jet of Hawking radiation

© NASA

Hawking radiation

Find out what can escape from black holes, the universe's ultimate prisons

According to quantum physics, throughout the universe there are endless pairs of subatomic particles that appear from nothingness and almost immediately disappear again. One of these has a negative mass and the other positive, which is why they instantly annihilate each other, but their existence for any determinable length of time is theoretically impossible.

However, Professor Stephen Hawking proposed that around a black hole something rather unusual happens. As in open space these two subatomic particles form, however they do not destroy each other. Instead, the negative mass particle is pulled into the black hole, while the positive one is fired out.

The latter exits in the form of measurable radiation, which is constantly ejected. This was coined 'Hawking radiation', and explains why black holes appear to glow extremely brightly as opposed to being totally dark. Interestingly, the negative-mass particles slowly eat away at the mass inside the black hole. Eventually they consume all of the mass within the entity, causing it to collapse and subsequently explode. While this occurrence has never actually been observed, it's now widely believed to be the eventual fate of almost all black holes.

No dice

Einstein wasn't a fan of quantum physics theories. Believing the universe to be more ordered, he once quipped: "God does not play dice." The discovery of Hawking radiation, however, led Professor Hawking to rebut, "God not only plays dice, but he sometimes throws them where they cannot be seen."

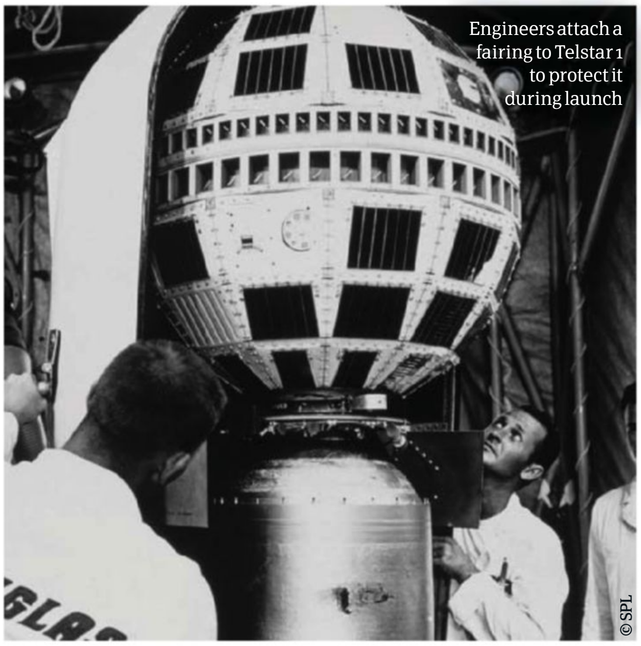
Telstar 1

How the world's first active communications satellite worked

Telstar 1 was a collaboration between NASA and American Telephone & Telegraph (AT&T), launched atop a Delta rocket on 10 July 1962. For the first time ever, it provided audio communication and simultaneous video between the USA, Europe and Japan, becoming the first active communications satellite capable of transmitting a signal.

The first passive communications satellite was NASA's 1960 Echo 1 balloon, which bounced signals off its Mylar structure that could be received around the world. Telstar 1 completed one orbit of the Earth in two and a half hours, which meant that it could only relay signals between two places for up to 40 minutes during each orbit when it was in line with more than one ground station.

Telstar 1 relayed its first public pictures on 23 July 1962, broadcasting images of the Statue of Liberty and the Eiffel Tower. It eventually went out of service on 21 February 1963. The cause of its demise was a series of nuclear bomb tests by the USA and USSR at the height of the Cold War, with the radiation from several explosions energising the Earth's Van Allen Belt and overwhelming Telstar 1's fragile transistors. However, today Telstar 1 remains in orbit around the Earth, the longest orbiting manmade satellite.



Engineers attach a fairing to Telstar 1 to protect it during launch

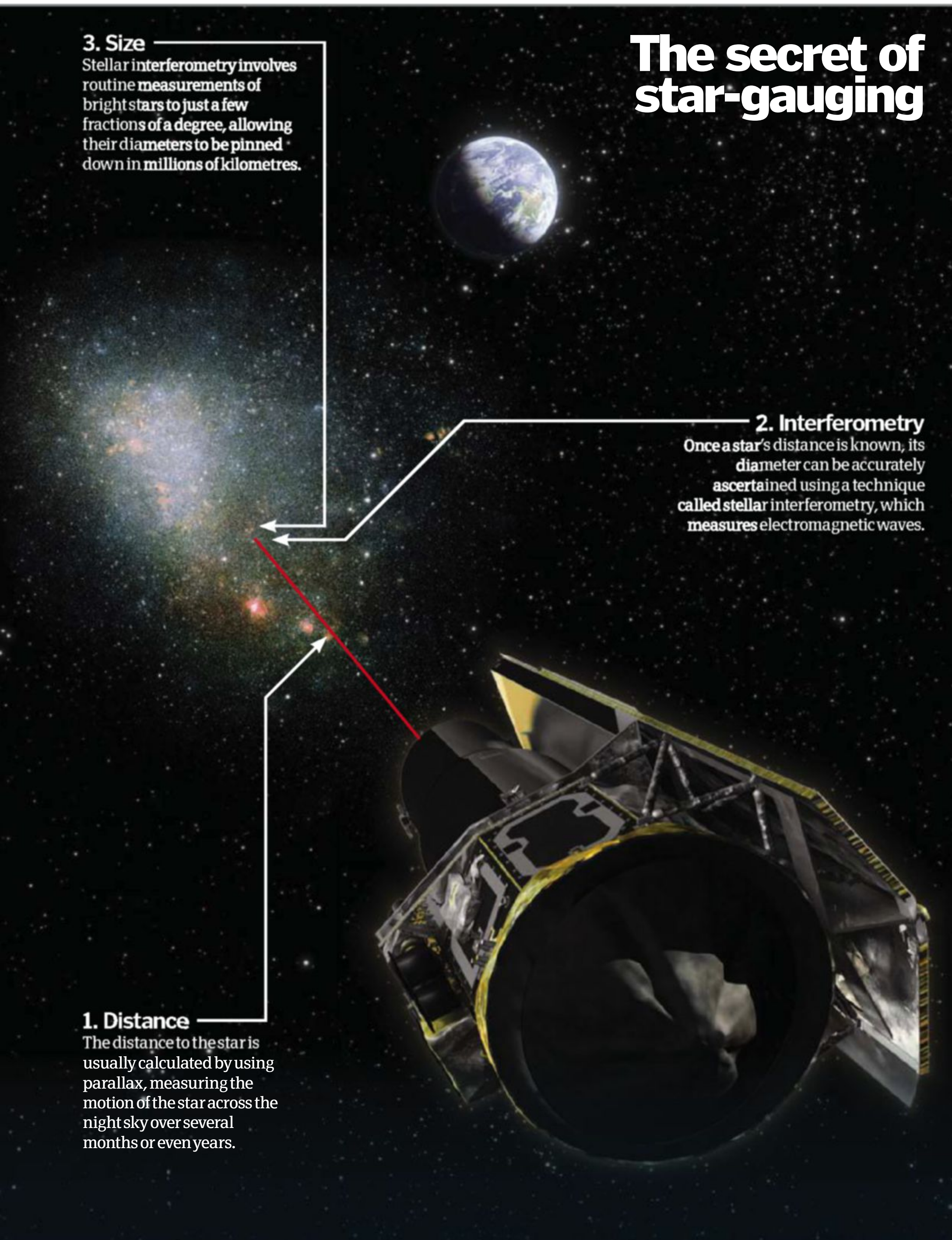
© SPL

3x © NASA

What's the biggest star?

The largest star in the universe that we know of is VY Canis Majoris, a red hypergiant star 5,000 light years from Earth. It is 2,100 times the size of our Sun and, if it were placed at the centre of our solar system, its surface would extend beyond the orbit of Saturn.

DID YOU KNOW? *The moon reflects just 11 per cent of the sunlight incident upon it*



Measuring stars

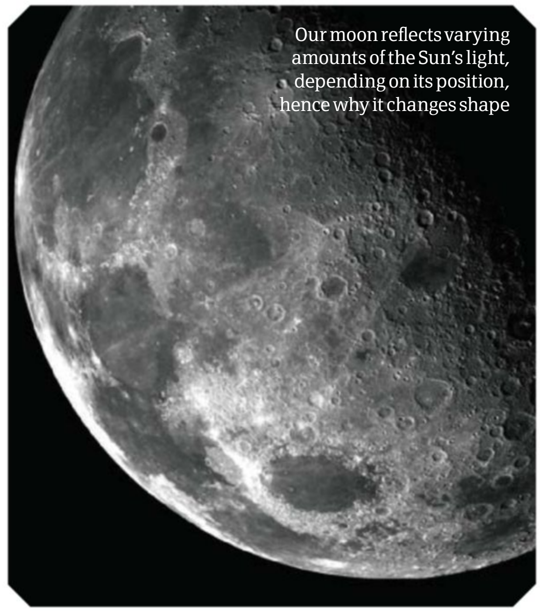
How do astronomers establish how big a star is?

To calculate the size of a star, astronomers need to initially establish several other factors.

First, its brightness at Earth must be calculated, followed by a measure of its distance from our home planet (which is also known as parallax). Next, its surface temperature must be ascertained; this calculation is made easier by stars of similar properties possessing near-identical compositions and temperatures.

Stars behave like 'black bodies', objects in the universe that glow at a particular wavelength or colour, depending on their temperature. Thus, once a star's temperature and brightness have been gauged, its surface area and diameter can be deduced based on previously confirmed data.

© NASA, JPL, Caltech, R Hurt



Our moon reflects varying amounts of the Sun's light, depending on its position, hence why it changes shape

Why does the moon shine?

We take a look at our natural satellite's eerie glow

Perhaps rather bizarrely, the moon is actually very dark, and it doesn't glow for the reasons you might think. The ancients thought that the moon produced its own light, but we now know definitively that this is not the case. Rather, our moon reflects the light of the Sun in accordance with its orbit.

The entire moon does not constantly reflect light – only the half in direct view of the Sun. As the moon is tidally locked to the Earth (ie we only ever see one face), our view of the lit half changes constantly, ranging from a disc to a thin crescent. On a full moon, the Sun is directly lined up with the Earth-moon line; when we see a thin crescent, on the other hand, the Sun is illuminating just the side.

However, the moon does not reflect light quite like a mirror, although it is similar. All objects in space have an albedo, which is a measure of how well they reflect light. To give you an idea of how this works, material like ice has a high albedo, whereas soil has a low albedo. However, the moon's albedo is actually very low – similar to that of coal. Its bright glow is instead the result of something called the opposition effect. You may have come across this when seeing a car's headlights shine on a dark road: the road appears brighter than it would if light were not incident upon it. The Sun plays the part of the headlight in this case, directly shining on the moon and leading to its bright glow. The large amount of debris on the surface of the moon also contributes to its reflectivity.

SUPERMASSIVE BLACK HOLES

Once thought impossible by scientists, supermassive black holes are now believed to be the heart and soul of every galaxy, powering trillions of stars while spanning an area no bigger than our solar system. Sound like science fiction? It's not. Read on to find out what this giant space phenomenon is all about…

Head to Head NEAREST BLACK HOLES

MINI


© NASA

1. Earth's atmosphere

Collisions between cosmic rays and particles in our very own atmosphere could be making thousands of miniature black holes.

MASSIVE


© ESO

2. V4641 Sagittarii

This black hole can be found just over 20,000 light years away in the Sagittarius constellation in a binary star system.

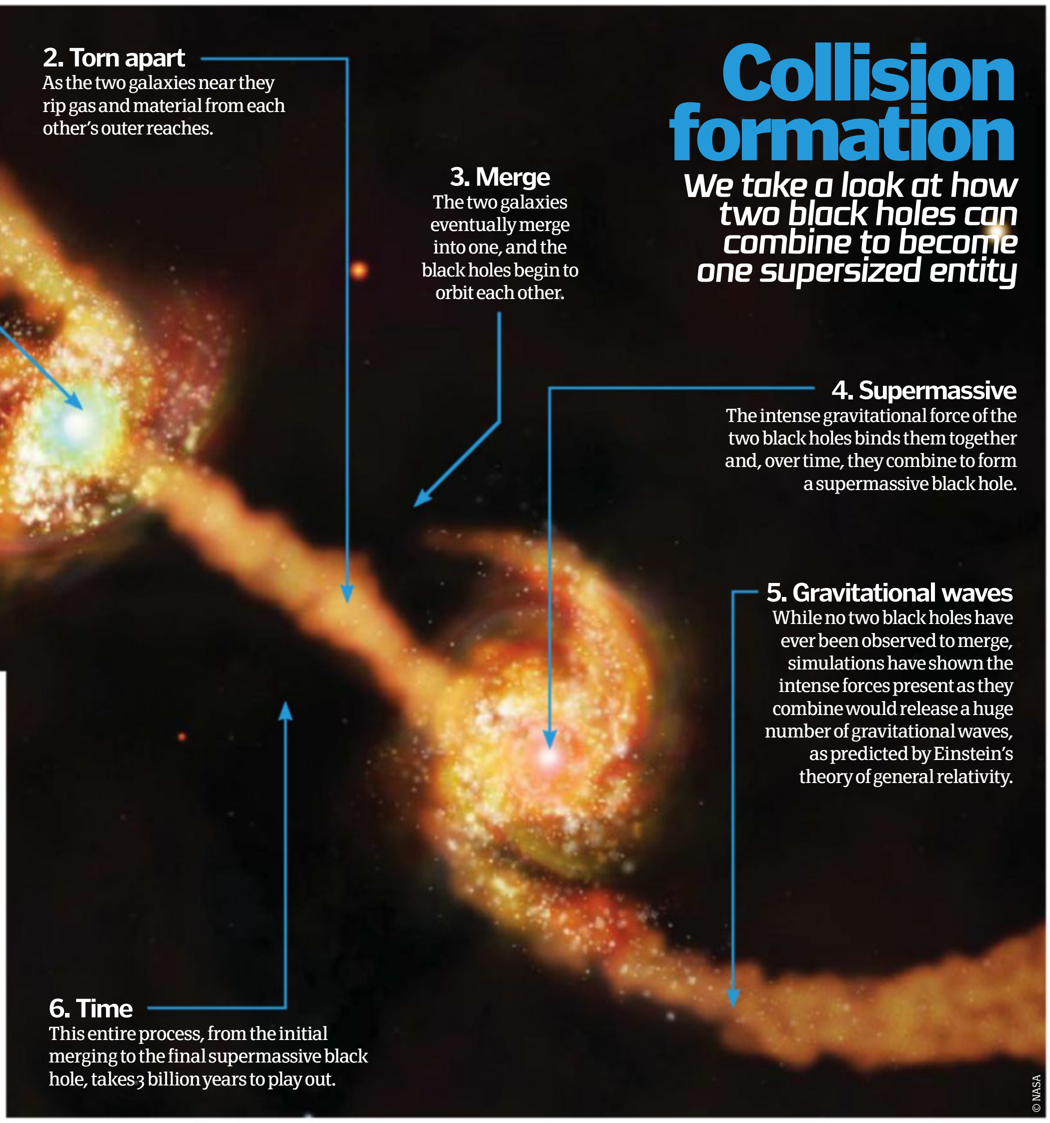
SUPERMASSIVE


© NASA

3. Sagittarius A*

This supermassive black hole is located at the centre of the Milky Way galaxy. It too is in the Sagittarius constellation and is approximately 26,000 light years from Earth.

DID YOU KNOW? About 15 per cent of the mass of a galaxy's central bulge is located within a black hole



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A supermassive black hole has the mass of at least a million suns

When black holes were first theorised, many scientists thought their existence was a physical impossibility.

How could an object exist from which nothing, not even light, could escape? And how could this phenomenon be large enough to power a galaxy? To this day many questions remain unanswered about these statistical nightmares, but there's little doubt now that they're real. But just how extraordinary are they?

As you might have guessed, a supermassive black hole (SMBH) contains a lot of mass, roughly equivalent to between a million or several billion suns. While regular black holes can be found propagating the universe as a whole, often left as remnants of a star going supernova, SMBHs are much less common but exceedingly more powerful. To date, every SMBH that has been discovered is located at the centre of a galaxy, indicating that this fascinating phenomenon is not only responsible for giving birth to and maintaining galaxies, but also destroying them. It is strongly believed that an SMBH lurks at the heart of nearly every galaxy, heating the stars and material in its vicinity in addition to recycling matter for the formation of new planets, stars and, in extreme cases, entirely new galaxies. Indeed, at the centre of our own Milky Way, 26,000 light years from Earth, resides the SMBH known as Sagittarius A*.

The realisation that supermassive black holes could be the power sources for galaxies got scientists wondering just how large these things could really become. In early December 2011 astronomers announced they had discovered the largest SMBH in the known universe. Located in the NGC 4889, or Caldwell 35, galaxy around 336 million light years from Earth, this SMBH contains the mass of 21 billion suns. Scientists analysed data from the Hubble Space Telescope, in addition to the ground-based telescopes Gemini North and Keck II in Hawaii, to find this behemoth. It eclipses the previous largest known SMBH by more than three times.

The reason these black holes can grow quite so big is due to the extreme conditions in which they are formed, with two primary methods currently favoured. The collision theory states that two or more colliding black holes can become gravitationally bound to create an SMBH, while quasar theory suggests newly forming galaxies will eventually pump so much matter into a regularly sized black hole that it will expand to a humongous size over a long enough period. Quasars are the expanses of matter surrounding a black hole and are regarded as the brightest objects in the universe. As a black hole pulls matter in, it swirls around it in a quasar stretching thousands of light years across.

At the very centre of a supermassive black hole is a phenomenon known as a singularity. This might be impossible to believe, but a singularity is no bigger than the full stop at the end of this sentence, but contains more mass than a billion suns. In fact, the exact physics of a singularity are nigh-on impossible to comprehend, and scientists continue to be baffled by these statistically impossible condensations of matter. Theoretically they contain the majority of the black hole's mass and thus are infinitely dense, but their existence is difficult to prove and so they remain highly controversial.

The gravitational pull this singularity – and ultimately the entire black hole – exerts is huge, to say the least. As mentioned previously, nothing can escape from a black hole, not even light itself. However, all hope is not lost if you stray too close.

Black holes go large

The extent to which a supermassive black hole's gravity is inescapable extends outwards several million miles to an area known as the event horizon. This is the point of no return, where once matter (and light) passes, it will no longer be able to get away. Surrounding the event horizon is the quasar. Depending on its age, however, something rather odd happens inside the event horizon of a supermassive black hole.

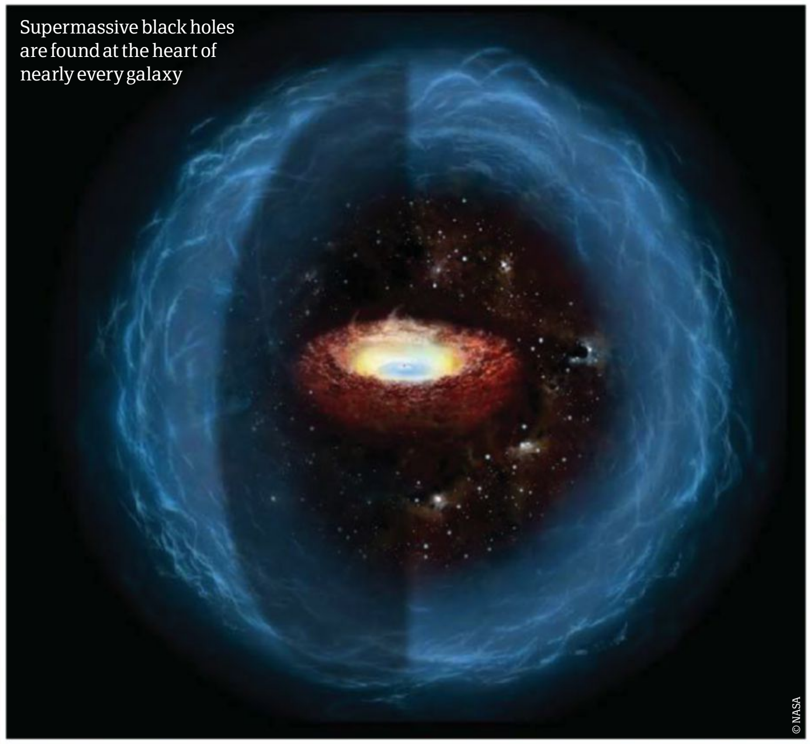
While black holes can consume a huge amount of energy and material, they cannot eat an infinite amount. Once it has reached its limit, it can no longer store matter, and instead fires material out vertically, in both directions, as giant jets of energy. These jets can be 20,000 light years across, sending huge amounts of energy (mostly X-rays) into the universe. It is via these jets that the majority of supermassive black holes have been found, as most galaxies can be observed to fire out these blasts of energy. However, as a galaxy ages, the SMBH will accrete less and less matter, eventually becoming almost stable as the remaining nearby material orbits the event horizon inside the quasar. At this point the jets will cease firing.

SMBHs have been around since the start of the universe, forming not only through the two methods we look at here but also through the combination of smaller and smaller black holes. At the dawn of the universe, roughly 14 billion years ago, large clouds of dust and gas drifted free. However, as proven by experiments at giant particle accelerators, such as the Hadron at CERN, the collisions between atoms produced mini black holes. Over time these would be pulled together by gravity into larger regular-sized black holes until, after hundreds of millions of years, supermassive black holes were created at the centre of these dust and gas clouds, in turn spurring the creation of new stars and subsequently entire galaxies.

These ancient but almost everlasting power generators might be terrifying to imagine, but there's little doubt that they're integral to both the formation and general upkeep of galaxies. It's unlikely we'll ever visit one ourselves, but from afar we can observe these cosmological wonders in the detail necessary to appreciate the job they do to keep the universe ticking over.

Quasar formation

Another theory of how supermassive black holes are formed is when a young galaxy reaches maturity. But how does this work in practice?



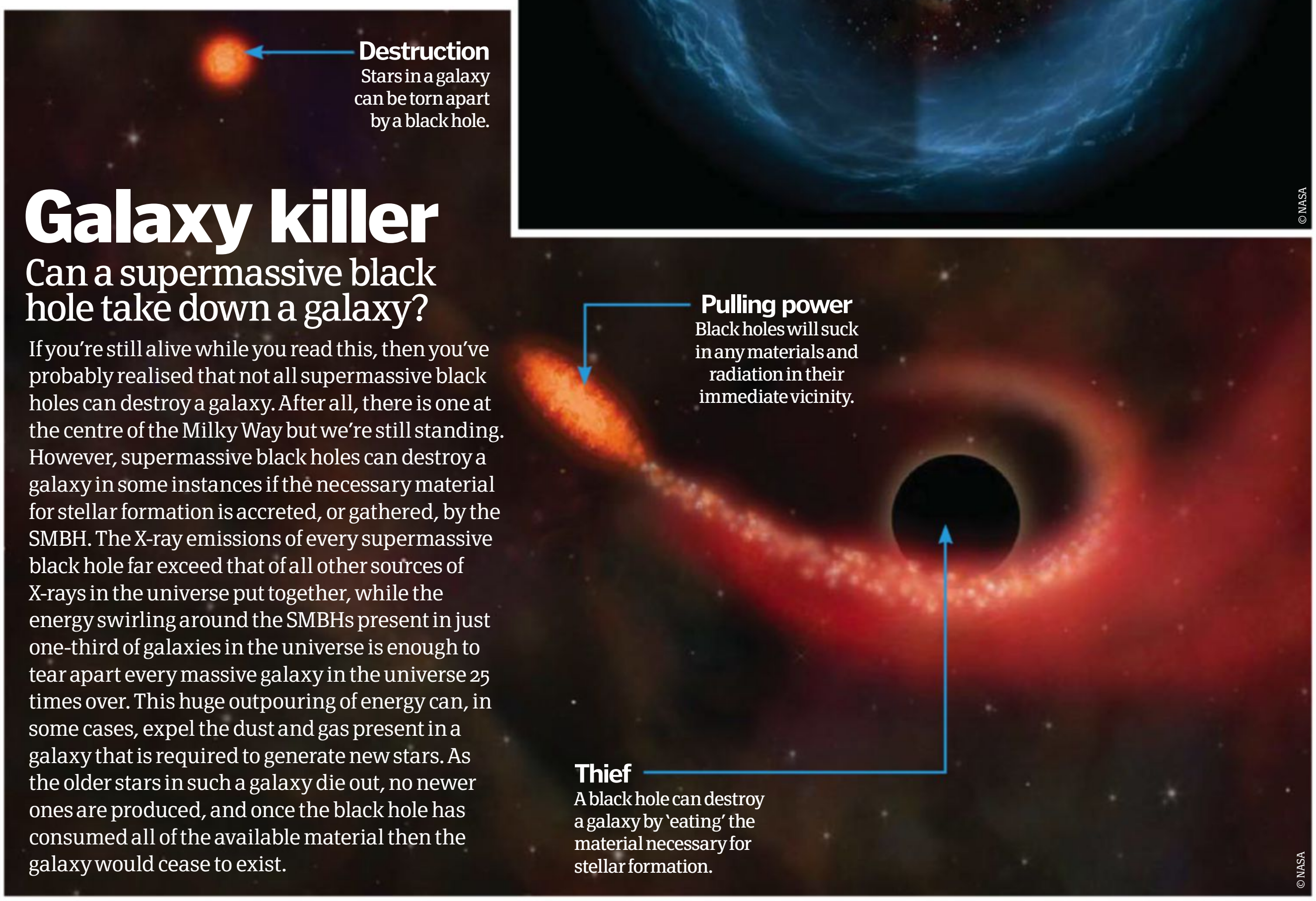
Supermassive black holes are found at the heart of nearly every galaxy

© NASA

Galaxy killer

Can a supermassive black hole take down a galaxy?

If you're still alive while you read this, then you've probably realised that not all supermassive black holes can destroy a galaxy. After all, there is one at the centre of the Milky Way but we're still standing. However, supermassive black holes can destroy a galaxy in some instances if the necessary material for stellar formation is accreted, or gathered, by the SMBH. The X-ray emissions of every supermassive black hole far exceed that of all other sources of X-rays in the universe put together, while the energy swirling around the SMBHs present in just one-third of galaxies in the universe is enough to tear apart every massive galaxy in the universe 25 times over. This huge outpouring of energy can, in some cases, expel the dust and gas present in a galaxy that is required to generate new stars. As the older stars in such a galaxy die out, no newer ones are produced, and once the black hole has consumed all of the available material then the galaxy would cease to exist.



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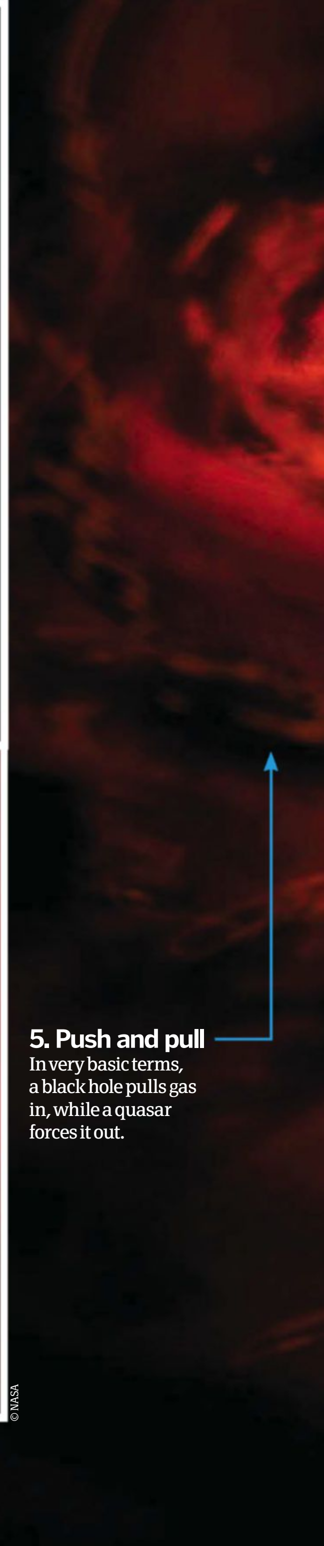


© NASA

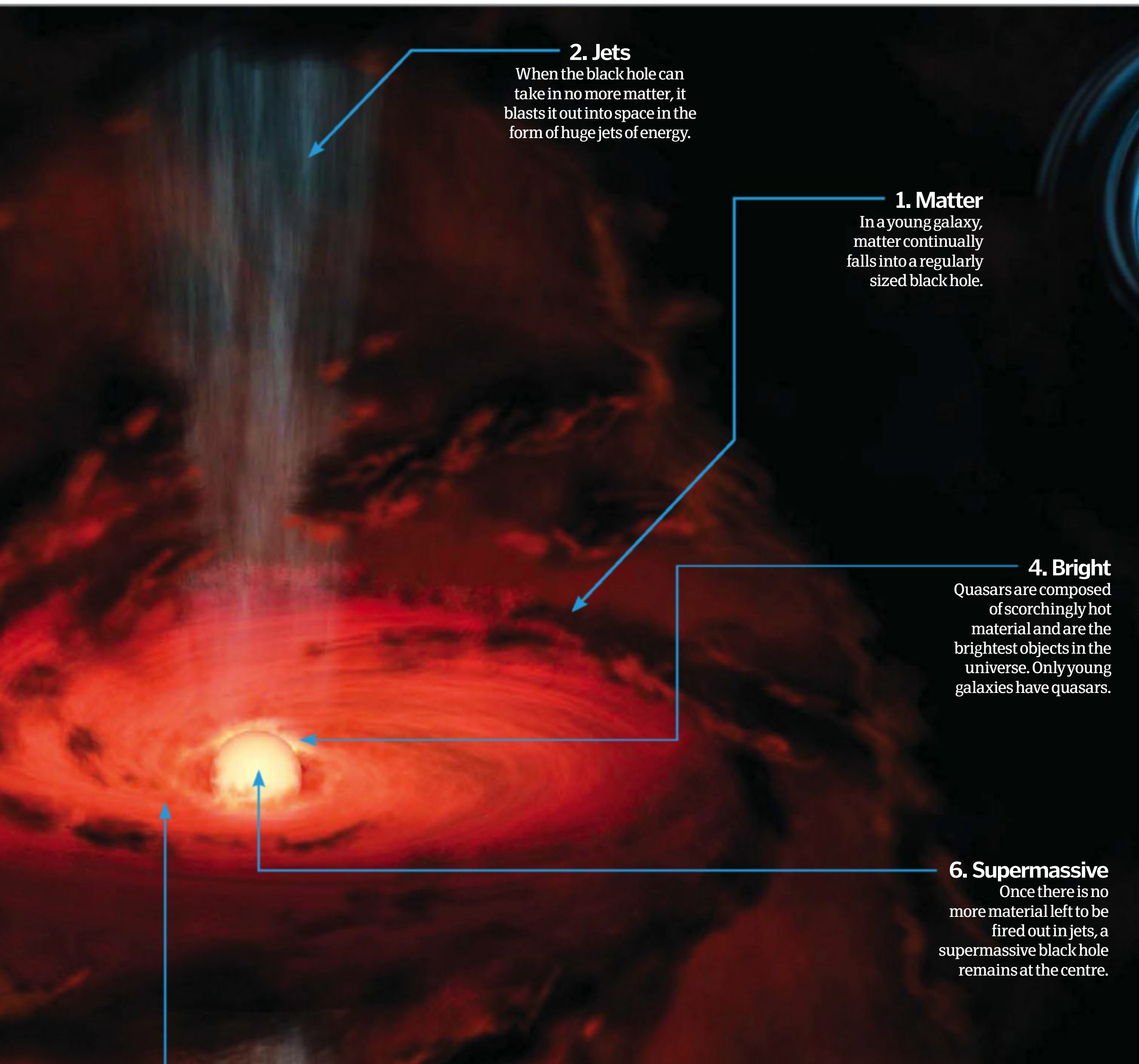
DID YOU KNOW?

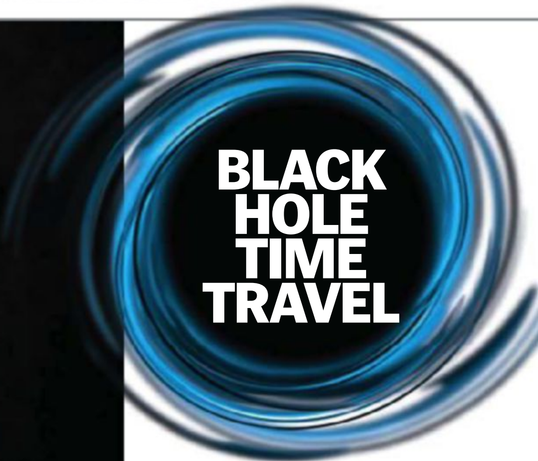
Could a black hole destroy Earth?

The estimated odds of the Earth being destroyed by a black hole are approximately one in a trillion. There is simply no black hole close enough to our solar system to swallow Earth and, even if a black hole with the same mass as the Sun took its place, Earth's orbit would not change.

© NASA

DID YOU KNOW? *If a star 1 million times the mass of the Sun collapses, it will form a supermassive black hole*





BLACK HOLE TIME TRAVEL

Could a supermassive black hole be used to travel forward in time? Stephen Hawking certainly thinks so. He suggests – theoretically – if a spaceship orbited a black hole 24 million kilometres (15 million miles) in diameter beyond the distance at which it would be pulled in (approximately a further 15 million miles), time would slow down for the crew on board. One full orbit would take the spaceship 16 minutes, according to observers watching from Earth, but for the crew each orbit would only take eight minutes. If they did this for ten Earth years, when they returned home 20 years would have passed. Hawking puts this down to the interaction with space and time, as the gravitational pull of an SMBH affects space-time and alters conditions for those in its vicinity.

The bright light at the centre of galaxies indicates the presence of an SMBH

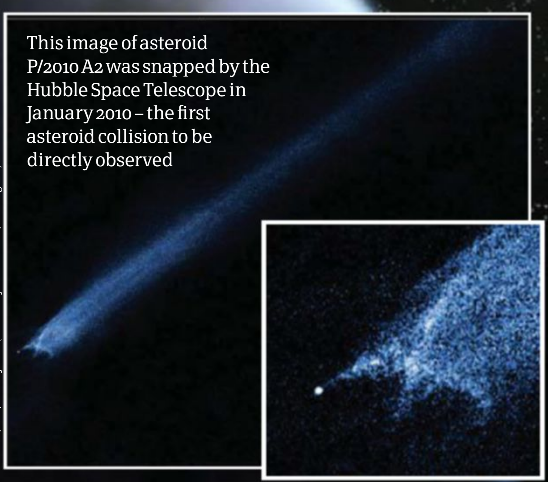
© NASA

Any star straying within the vicinity of a black hole will likely be torn apart

© ESO

Asteroid collisions

What happens when one asteroid impacts another?



This image of asteroid P/2010 A2 was snapped by the Hubble Space Telescope in January 2010 – the first asteroid collision to be directly observed

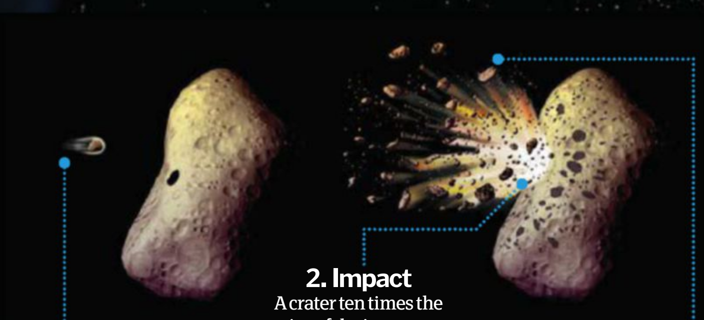
Throughout the solar system, there are potentially millions of asteroids – rocks left over from the formation of the solar system some 4.5 billion years ago – just waiting to be discovered. Some will have been ejected from a planet following a collision, such as the Pluto-sized object believed to have crashed into Mars early in its formation. Others are the remnants of failed planetary formation, often unsuccessful due to the effects of a nearby body. One culprit, Jupiter, prevented the formation of another planet between itself and Mars, leaving the asteroid belt.

With millions of asteroids travelling through the solar system – many of these confined to the Kuiper belt beyond Neptune and the aforementioned asteroid belt – it is often thought that collisions between them are frequent. Indeed, many works of fiction portray asteroid belts as dense areas of rock that are difficult for a spacecraft to traverse. However, this is anything but the case. Asteroid collisions are very, very rare. The chance of two colliding is roughly equivalent to winning the lottery every day for a week. Only one direct collision between two asteroids has ever been observed, with thanks going to the Hubble Space Telescope in January 2010. It will most likely be many years before another is seen, but that doesn't make the study of these collisions any less important. On the contrary, by having an advanced knowledge of what to expect if we see two asteroids collide, or seeing the aftermath of a collision we may have missed, we'll be able to glean more information about their composition, origin and importance in the solar system the next time we witness a collision.

TYPES OF COLLISION

There are many more small asteroids in the solar system than large ones, so it is extremely unlikely that two large asteroids of comparable size will ever hit one another. Instead, the collision of a small asteroid with one more than 50,000 times bigger is more common. For every million asteroids that are 0.1 kilometres (0.06 miles) wide, there are only 1,000 wider than one kilometres (0.6 miles), and just one bigger than ten kilometres (six miles). For this reason, as seen in our diagrams, cratering is much more common than fracturing, which happens more regularly than shattering.

CRATERING

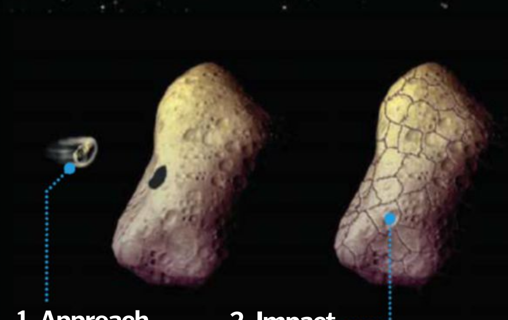


1. Approach
Cratering occurs when the incoming asteroid is less than 1/50,000th the size of the larger body.

2. Impact
A crater ten times the size of the impactor forms on the surface.

3. Debris
Ejected debris falls into the same orbit around the Sun as the asteroid, and thus can hit it again.

FRACTURING



1. Approach
If the incoming asteroid is exactly 1/50,000th the size of the larger asteroid, it will cause a fracturing collision.

2. Impact
Most of the energy in the collision is used up in breaking the larger asteroid into pieces, forming cracks across the surface.

COLLISION

© SEDS D. Seal

1. Shoemaker-Levy
In July 1994, Comet Shoemaker-Levy 9 collided with Jupiter, providing the first observation of such a collision in our solar system.

FATALITY

© NASA

2. Nakhla
In 1911, a meteor landed in Nakhla, Egypt, apparently killing a dog. If this myth is true, it is the only recorded meteor fatality.

MAN-MADE

© NASA/JPL

3. Tempel 1
NASA sent an impactor probe crashing into the comet Tempel 1 in 2005. This was the first mission to artificially eject material from a comet.

DID YOU KNOW? At least one new asteroid has been discovered every year since 1847

Asteroids vs comets

What's the difference between asteroids and comets?

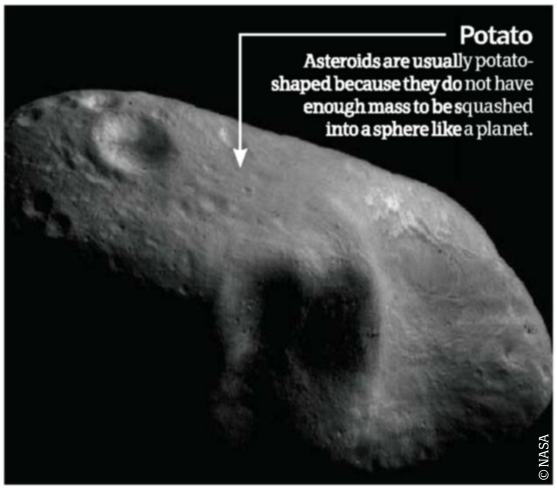
Asteroids and comets are both remnants of the early formation of the solar system 4.5 billion years ago. As of August 2011, there were less than 4,500 known comets in the solar system, compared to over 550,000 known asteroids (although there are thought to be many millions more).

Asteroids are composed of rocky material and metals, while comets are made of ice. As a result, asteroids formed nearer the Sun than comets, because ice could not remain solid at a close distance. Comets that formed further out and later approached the Sun lose material with each orbit because the ice melts, forming a tail behind the body. Asteroids, on the other hand, do not lose material, and thus do not have a tail.

Comets are often found in large elongated orbits extending outwards up to 50,000 times the distance from the Earth to the Sun. By comparison, Neptune – the furthest planet of the solar system – is just 30 times further from the Sun than the Earth. Concurrently, asteroids are usually found following a circular orbit around the Sun and they tend to group together in belts, such as the asteroid belt found between Jupiter and Mars, which was formed when the gravitational pull of Jupiter prevented the asteroids from forming into another planet.

> "Asteroids are composed of rocky material and metals, whereas comets are made of ice"

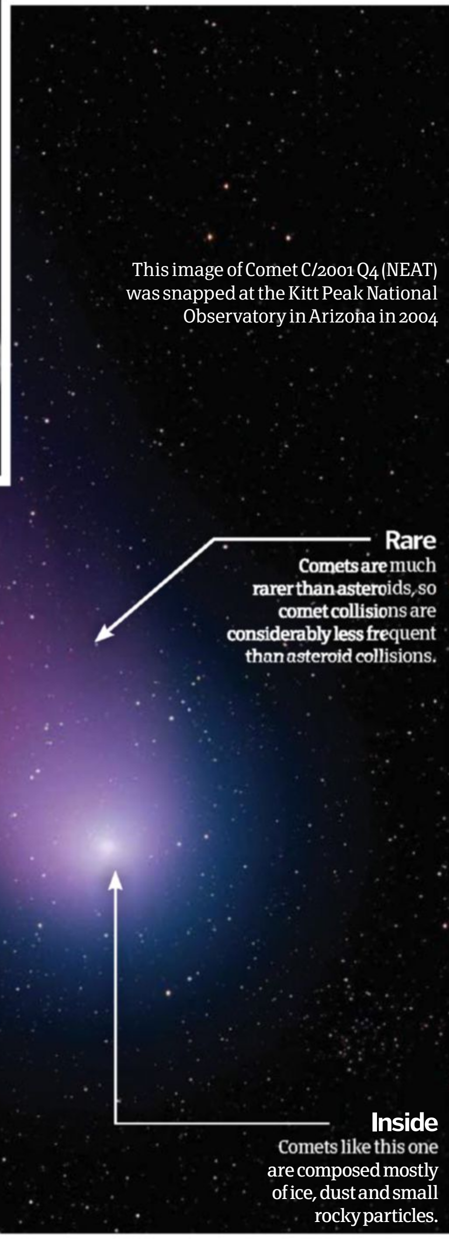
© NASA



Potato
Asteroids are usually potato-shaped because they do not have enough mass to be squashed into a sphere like a planet.

© NASA

Above is Eros, the first asteroid known to enter the orbit of Mars



This image of Comet C/2001 Q4 (NEAT) was snapped at the Kitt Peak National Observatory in Arizona in 2004

Rare
Comets are much rarer than asteroids, so comet collisions are considerably less frequent than asteroid collisions.

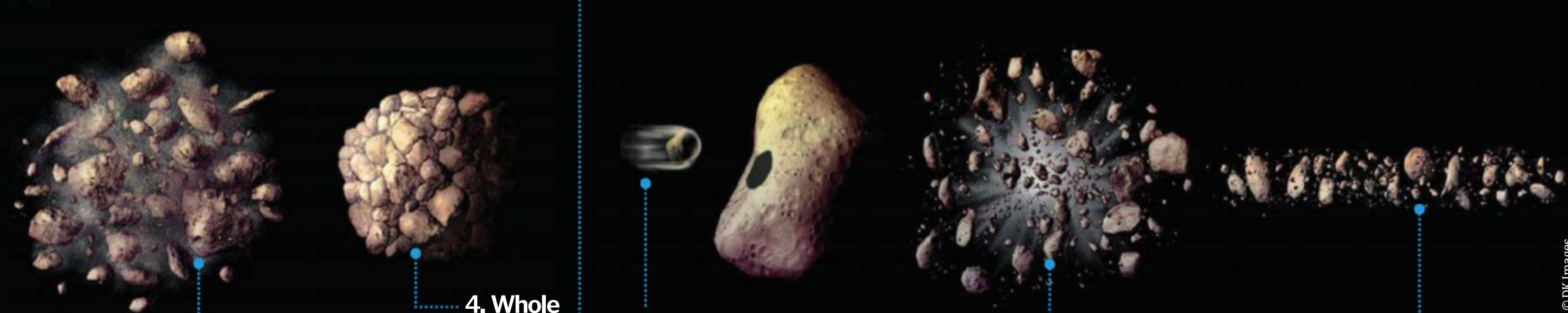
Inside
Comets like this one are composed mostly of ice, dust and small rocky particles.

© T. Rector (University of Alaska Anchorage), Z. Levay and L. Frattare (Space Telescope Science Institute) and National Optical Astronomy Observatory/Association of Universities for Research in Astronomy/National Science Foundation

Ice on comets melts as they travel towards the Sun, leaving a tail

© NASA

SHATTERING



1. Approach
The larger asteroid will be shattered into pieces if the incoming asteroid is more than 1/50,000th its size.

2. Impact
Like fracturing, the asteroid is broken up into pieces, but there is enough energy for the fragments to escape its gravitational pull.

3. Debris
The resultant debris will form a group of smaller asteroids around the same orbit as the original asteroid.

4. Whole
To an observer, it is not obvious that the asteroid is in pieces, instead appearing to be an intact asteroid.

3. Debris
The resultant fragments don't have enough energy to escape the gravitational field of the others, so they reform into a ball of rubble.

© DK Images

Cosmic exclamation point

The two colliding galaxies that strikingly resemble a punctuation mark

Shown here is galaxy VV 340 North above VV 340 South – collectively known as just VV 340 (or Arp 302) – with the former being imaged side-on, and the latter head-on. The resultant image of the two galaxies, which are approximately 450 million light years from Earth, coincidentally bears some resemblance to an exclamation mark due to the positioning of the two galaxies relative to us.

VV 340 North is classified as a luminous infrared galaxy (LIRG) because of the large amount of infrared light it gives off. In fact, LIRGs emit energy hundreds of times faster than typical galaxies, such as our own Milky Way. It is likely that a surpermassive black hole – a dense singularity with a mass greater than 1 million suns – is the source of energy at the centre of VV 340 North, and indeed other LIRGs as well. Most of the ultraviolet and short-wavelength optical emissions from the galaxy pair come from VV 340 South, suggesting that it contains much more actively forming newborn stars than VV 340 North, which contains much older stars. Therefore, the collision of these two galaxies in a few million years will result in something akin to a merger between a young and an old galaxy, and it is likely that the older galaxy will come out on top due to its greater mass.

This image is the combination of data from NASA's Chandra X-ray Observatory and the Hubble Space Telescope

Tidal locking explained

Why can we only see one face of the moon?

On Earth the same 'face' of the moon always points in our direction. Likewise, the opposite side – commonly known as the 'far side of the moon' – always faces away from us. This is because in the time it takes our satellite to orbit the Earth it completes almost exactly one revolution, so it is always aligned in this way.

This phenomenon is due to a process evident throughout the solar system, known as tidal locking. The Earth and the moon are locked gravitationally. They both pull on one another, which is the cause of tides on Earth. As the moon orbits the Earth, it pulls the part of Earth it is above towards it and creates a 'bulge'. This is noticeable on water, which is flexible, but not so on rock, which is rigid, causing parts of oceans and seas to rise where others do not. Over time, since the formation of the moon at about the same time as Earth 4.6 billion years ago, this process has slowed the rotation of the moon, as the friction caused by the gravitational pull prevented it from rotating. For this reason the moon is now locked in an orbit above Earth where one face always points towards us.

© JPL

Why Uranus has unusual rings

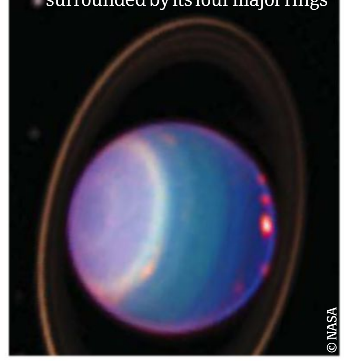
What's going on around this outer planet?

The 13 known rings of Uranus are very faint and were not known to exist until they were discovered in 1977 by a team of scientists, and later observed in more detail by the Voyager 2 spacecraft in 1986. Unlike the rings of other planets like Saturn, which are composed of a fine dust that reflects sunlight, the rings of Uranus consist of small boulders measuring 0.2-20m (0.7-66ft) across that reflect minimal sunlight, a major factor in their late discovery.

One reason for the large size of the ring material is that the rings are very young – no more than 600 million years old (Uranus formed roughly 4.6 billion years ago) – so they have not had much time to be broken down. They were created by one or several moons of Uranus being torn apart by its gravity, with the resultant debris being left to orbit the planet and 'shepherded' into rings by other moons.

They range from a distance of about 39,000km (24,200 miles) from the centre of the planet to over 97,000km (60,300 miles) and are each just a few kilometres thick. There is no detectable material in between them, due to the shepherding effect of the nearby moons.

The Hubble Space Telescope snapped this false-colour image of Uranus surrounded by its four major rings



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Slingshot orbits

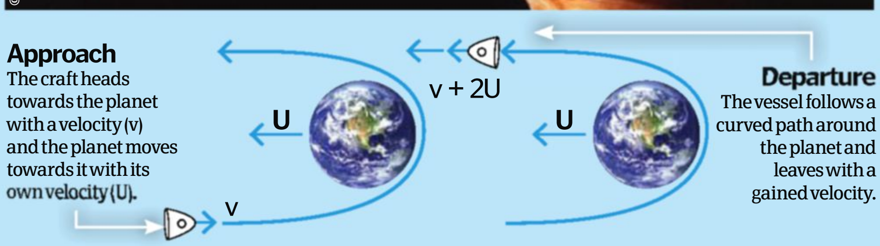
How spacecraft go further and faster using planet fly-bys

When a modern spacecraft travels to a planet in the solar system, it cannot complete its journey on rocket fuel alone. Too much is needed to traverse large distances (further than the moon) and so spacecraft must rely on gravity assist techniques, or 'fly-bys', to cover the great distances involved. Gravity assist manoeuvres take advantage of the gravitational influence of a planet and use this substantial force to accelerate in a particular direction.

If a spacecraft approaches a planet in the same direction as its orbit, it will gain speed as it moves towards the planet. This is because the vehicle is pulled towards the planet by its gravity and, as it encircles it and travels away, it retains the speed it has gained.
However, the spacecraft cannot just fly straight towards the planet.
If this were to happen, the speed gained by gravity assist would be lost in equal amounts because the gravity of the planet would also pull back the craft as it left.
Therefore spacecraft must travel in a hyperbola, or a U-shape, around the planet, in order to maximise the speed gain and, simultaneously, minimise the speed loss.

© NASA

Both Voyagers 1 and 2 used slingshot orbits to reach the outer planets



DEADLY SOLAR STORMS

Discover why huge explosions from the Sun can cause major problems on Earth

Weather isn't just a phenomenon for Earth's atmosphere; there's an entirely different type of weather occurring out in the space between Earth and the Sun, thanks to changes in the latter's magnetic activity cycle. Among other things, this cycle modulates powerful outbursts from the Sun's surface that can have a direct impact on our lives. These are known as geomagnetic, or solar, storms.

Solar storms can also include a wide range of related phenomena, including auroras and electromagnetic emissions as well as solar energetic particle events, solar flares, and coronal mass ejections. Some of these have little effect on Earth.

5 TOP FACTS WEIRD SOLAR ACTIVITY

Black hole sun

1 The Sun gets holes in its corona. These areas are darker and colder than the surrounding area and have open magnetic field lines, allowing for solar wind to develop.

Solar tsunamis

2 Solar flares generate massive, fast-moving shock waves on the corona known as Moreton waves. They can move as fast as 1,500 kilometres (932 miles) per second.

Loop the loop

3 Cooled plasma can loop 700,000km (435,000 mi) from the Sun's surface in a formation known as a solar prominence. They can break off and form coronal mass ejections.

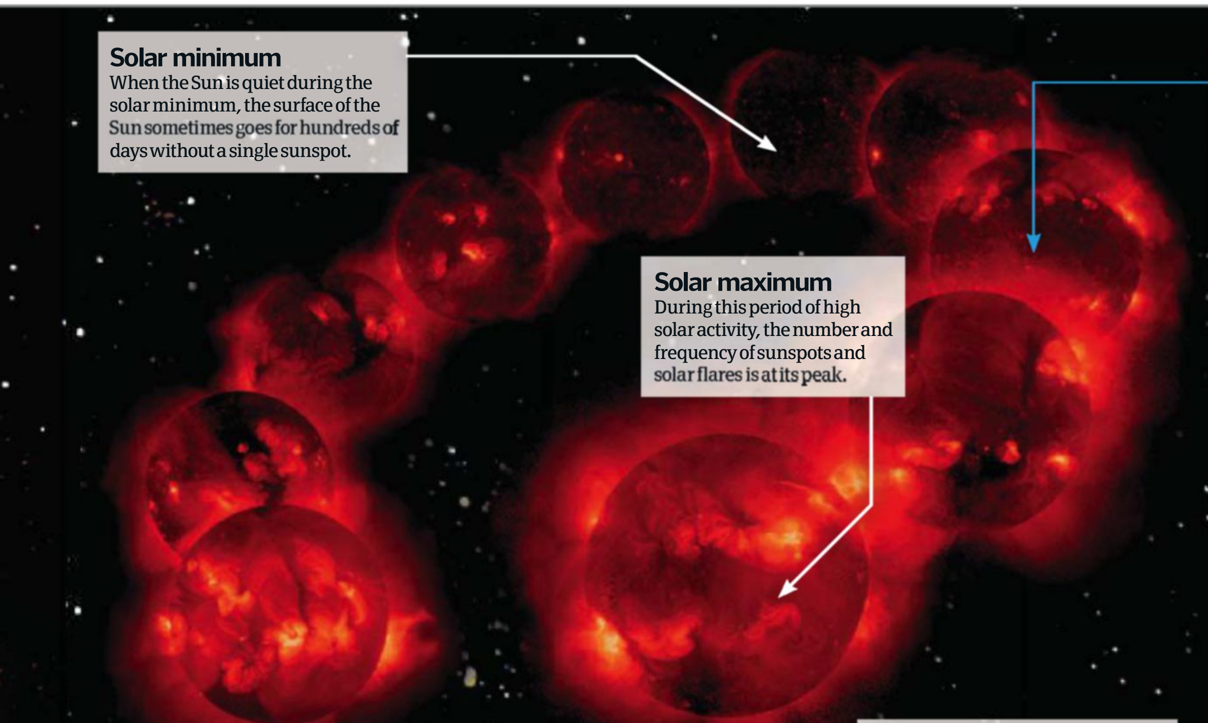
Parker spiral

4 Thanks to the influence of solar wind, the Sun's magnetic field takes on the shape of an arithmetic spiral as it rotates and extends throughout the solar system.

Somersaulting Sun

5 During the solar maximum, the Sun's poles switch – the north pole points south and vice versa – as increased sunspot activity causes its magnetic field to change.

DID YOU KNOW? *Some estimate that a super solar storm could cause $2 trillion USD in damage*

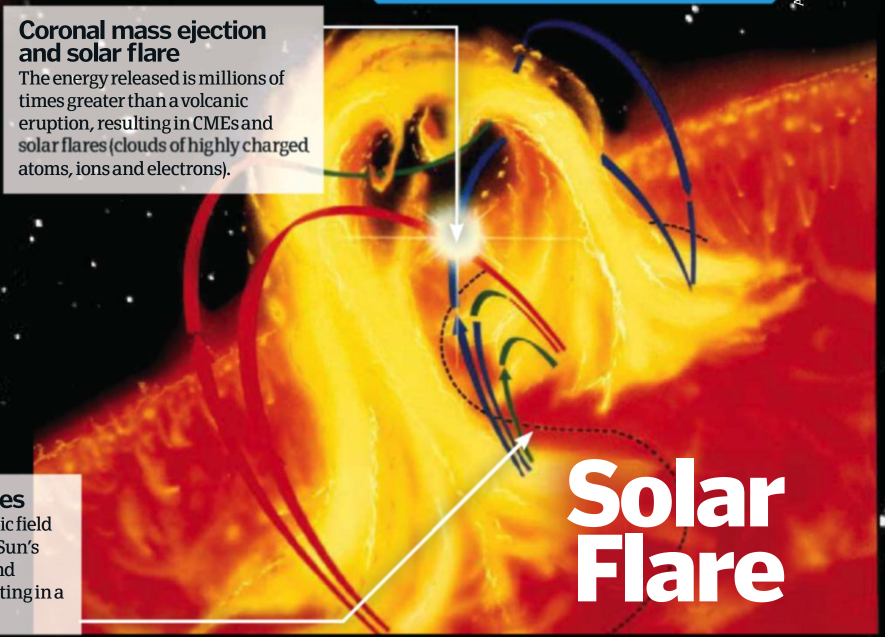


The solar cycle

Sunspots are temporary dark spots of intense magnetic activity on the Sun's surface. They change according to a cycle that lasts roughly 11 years. Clustered into two bands around the Sun's mid-latitudes, they move closer to the equator over the course of the cycle. During the cycle, the period of fewest sunspots is the solar minimum, while the time of greatest activity is the solar maximum. This cycle has been a quiet one, with 50 per cent less activity than predicted. However, astronomers believe we are now approaching solar maximum, with the apex occurring in 2013, and wonder if the Sun might make up for lost time with more intense solar storms.

> "Large solar storms have the potential to cause serious damage"

Not all solar storms affect Earth

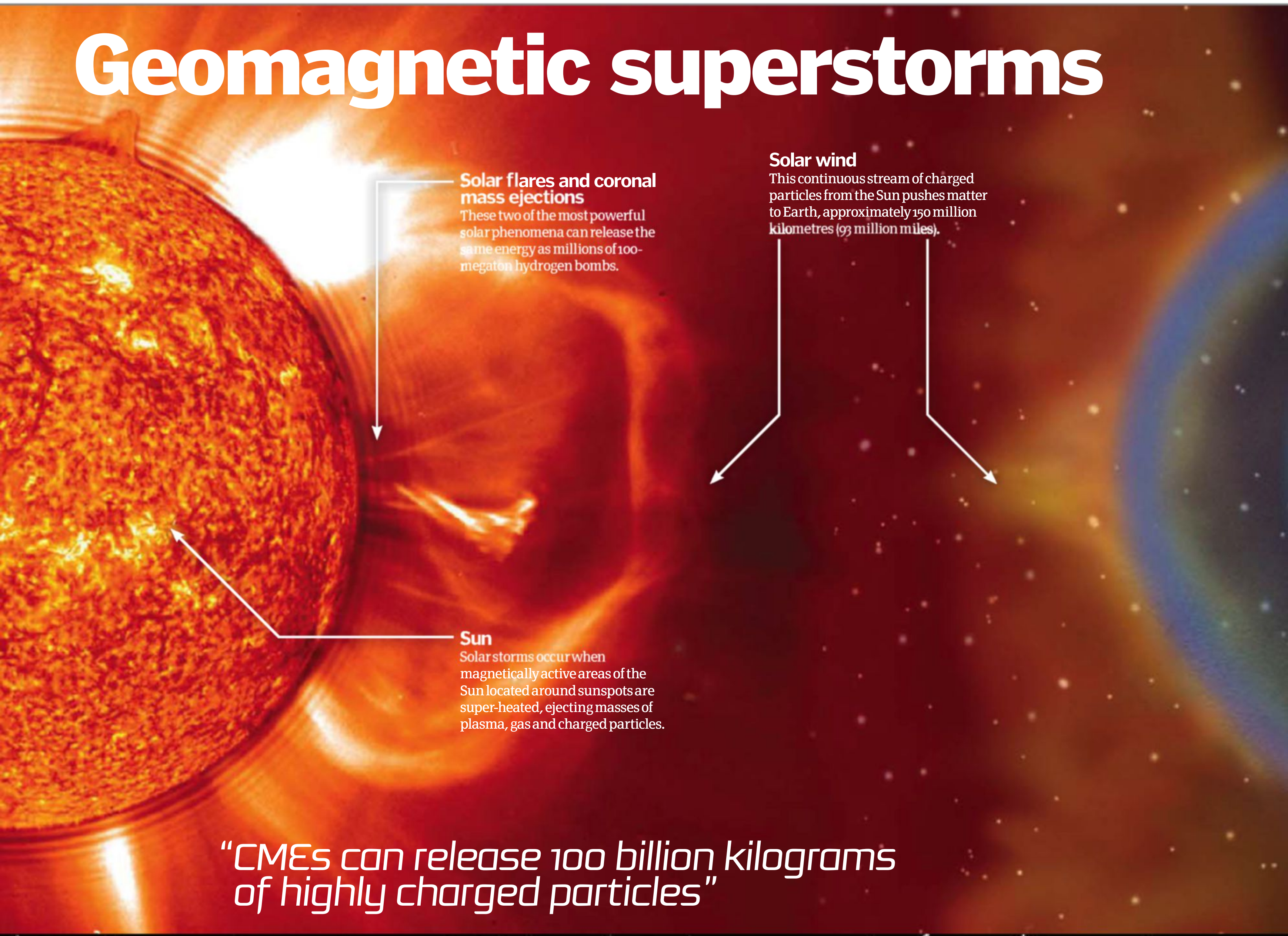


For example, charged particles driven into the Earth's upper atmosphere by solar wind impact with atoms and create the beautiful, luminous glow known as the auroras in the high-latitude areas of the Northern and Southern Hemisphere. However, not all space weather phenomena is innocuous – some can even be fatal. A solar proton event (SPE) has the ability to endanger the life of astronauts. SPEs are a type of cosmic ray that occurs in conjunction with other solar storm phenomena such as solar flares. Comprising electrons, protons, and heavy ions that are extremely high-energy, some SPEs can be as fast as 80 per cent the speed of light. The resulting radiation can damage DNA and increase astronauts' risk of cancer and other diseases. At high, prolonged doses, exposure can lead to death. In addition, the sensitive instruments on spacecraft can be affected, causing problems with navigation or power. Very high-energy solar proton events can theoretically even harm passengers on high-altitude aircraft flights.

But what happens when an event has a direct impact on us here on Earth? A coronal mass ejection (CME) occurs when the Sun releases a huge burst of charged particles known as solar wind, along with plasma and radiation, from a cluster of sunspots. Depending on the velocity at which it was released, a CME can reach the Earth's magnetosphere, or magnetic field. The highly charged particles of solar wind can be powerful enough to cause a shock wave and disturb the magnetosphere. The resulting release of plasma and radiation, while not biologically dangerous (our atmosphere absorbs the most harmful radiation), can disrupt everything from power grids and oil drilling on the ground to communications and GPS satellites in the atmosphere.

In 1859, the largest solar storm ever recorded hit Earth. Named the Carrington Event in honour of the astronomer who first viewed it, this storm started with a solar flare. This led to a CME that travelled to Earth in 18 hours (as opposed to the three or four days that they typically take). Because we're so reliant upon high-tech electronic systems, powerful solar storms like the Carrington Event have the potential to cause serious damage. Subsequent storms have had serious effects. In 1960 there was another solar storm that caused widespread radio blackouts. A more intense storm in 1989 left 6 million people in the dark in Quebec when a power grid failed – but we have yet to experience another superstorm like that in 1859.

Geomagnetic superstorms



"CMEs can release 100 billion kilograms of highly charged particles"

Super-strong storms

Solar storms and the resulting phenomena can be amazingly powerful, especially solar flares and coronal mass ejections. Solar flares and CMEs can release the same amount of energy as millions of 100-megaton hydrogen bombs exploding at once. The largest ones emit up to 1032 ergs, which is 10 million times the energy released during an average volcanic explosion on Earth. CMEs can also release 100 billion kilograms (220 billion pounds) of highly charged particles at a speed of 1,000 kilometres (621 miles) per second.

The largest solar storms emit 10 million times more energy than a volcanic explosion

Head to Head
EXTREME SUN EFFECTS

DEADLY

1. Ultraviolet radiation

Exposure to UV rays can cause skin cancer, including melanoma, which accounts for 75 per cent of skin cancer deaths.

DEADLIER

© Jen, 2009

2. Electromagnetic radiation

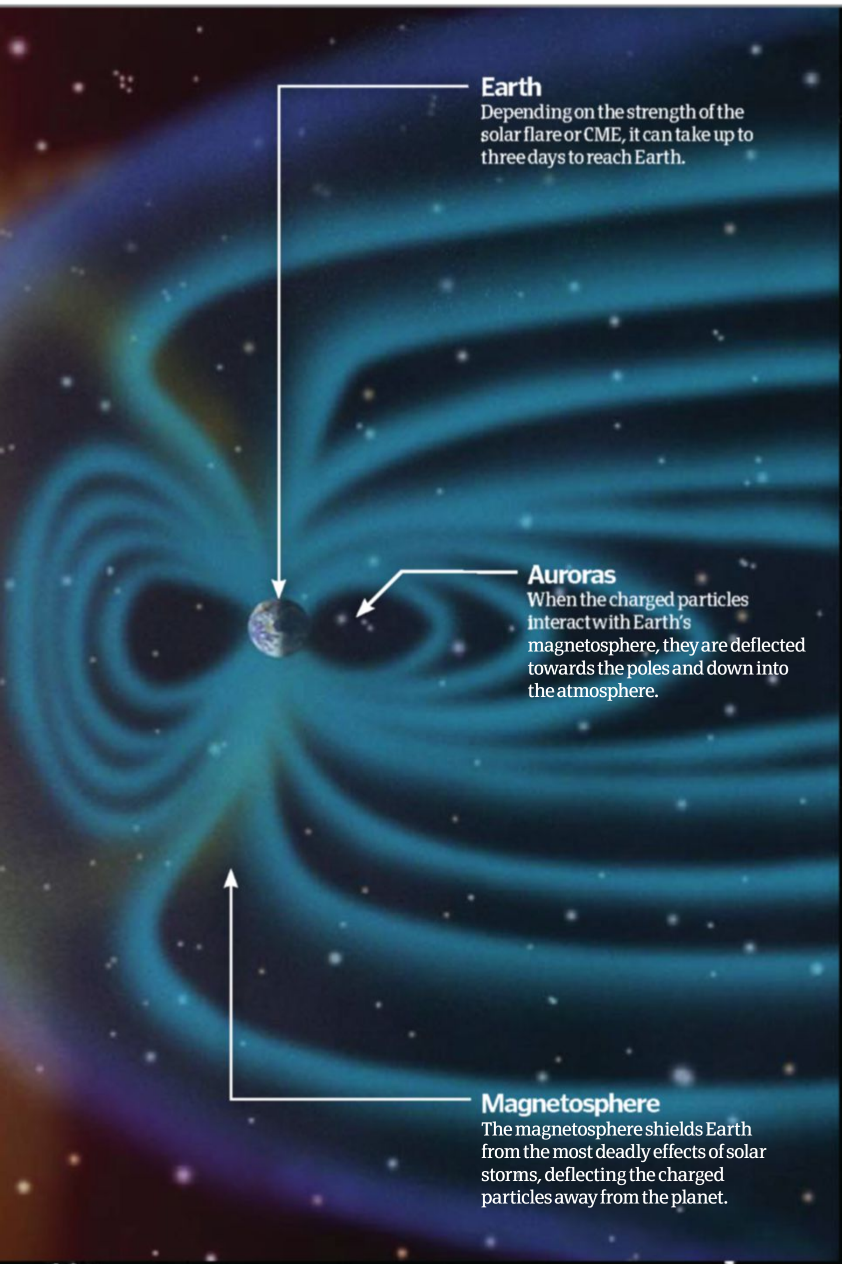
The loss of power and communications from a severe solar storm has the potential to cause numerous deaths around the world.

DEADLIEST

3. X-Class solar flare

An astronaut standing on the moon during these strongest of solar flares could die instantly from radiation poisoning.

DID YOU KNOW? During the Carrington Event, some telegraph operators could still send messages due to the storm's currents



Super solar storm effects

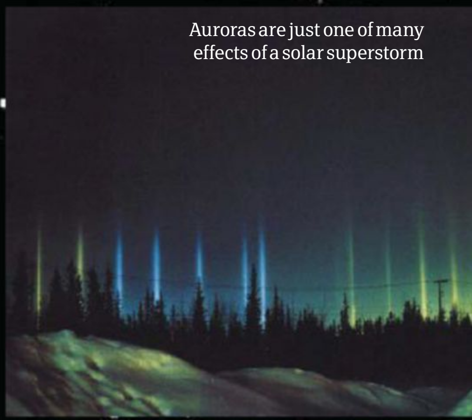
The Carrington Event, the most severe solar storm ever recorded, wreaked havoc from 28 August to 2 September 1859. Telegraph systems in North America and Europe were disrupted by the powerful electrical currents. They electrocuted telegraph operators, while snapped wires sent out sparks and set fires. Intense red and green auroras were reported in places they'd never been seen before, including the Rocky Mountains and the Caribbean.

A storm like the Carrington Event would have a much greater effect on our society. Radios, for example, rely on reflections of waves off the ionised gas in the Earth's ionosphere. Intense radiation disrupts the gas and prevents reflection, rendering radios useless. Air heated by intense ultraviolet emissions would rise and increase the density of the gasses in low-Earth orbit, putting drag on satellites stationed there and causing them to slow down or even fall out of orbit entirely. The flood of charged ions and electrons would also cause electronic overloads, either damaging or disabling the satellites entirely. Electronic currents entering power lines could overload transformers and generators and blow them out. Travel would come to a standstill as planes would be unable to navigate and power grid failures could leave people in the dark for weeks or even months.

"Auroras were seen in places they had never been before"

The main effects of a solar superstorm

- Auroras
- Radio and TV blackouts
- Mobile phone tower failures
- Astronauts and satellites at risk
- Power grid failure
- Networks offline
- Phantom currents in power lines
- Hardware damaged
- Air travel crippled
- Banking systems down
- Exploding gas lines

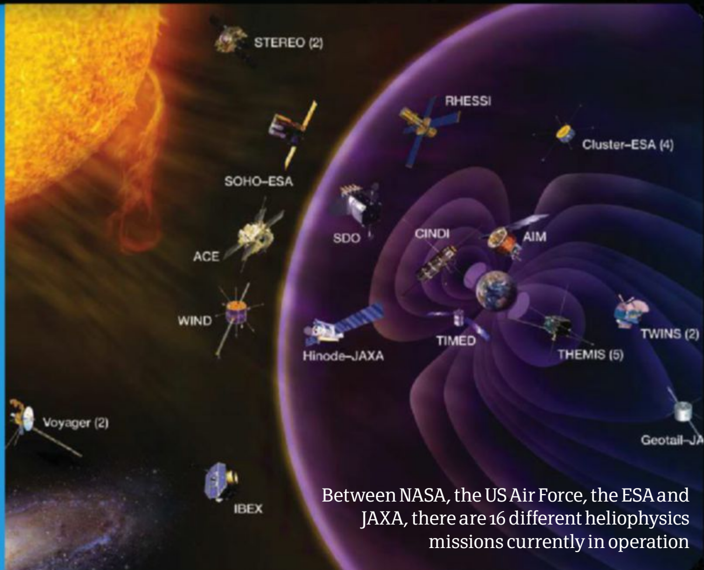


Auroras are just one of many effects of a solar superstorm

Space weather forecasts

NASA has several different spacecraft and satellites in place to report on space weather. These include two spacecraft orbiting on opposite sides of the Sun, known as STEREO (Solar Terrestrial Relations Observatory), that can provide stereoscopic images of 90 per cent of Sun's surface to catch the first signs of activity such as CMEs and solar flares.

The Solar Dynamics Observatory (SDO), gives readings of the Sun's magnetic activity, UV output and images from near Earth. Finally, the satellite known as ACE monitors solar wind and radiation, with the ability to give a 30-minute warning before a storm hits the Earth. Accurate space weather forecasts can give us the time to do things like divert planes, put satellites and communications hubs into 'safe' mode, and even identify and disable power transformers that are most at risk.



Between NASA, the US Air Force, the ESA and JAXA, there are 16 different heliophysics missions currently in operation

Hypernovas

How one of the most destructive forces in the universe works

A hypernova, also known as a collapsar, is an extremely energetic supernova. The two are not to be confused, even if their formation is very similar. In a supernova, a star shears off its outer matter but leaves a new star at its centre, often a neutron star. In a hypernova, the force of the explosion tears the inner star apart too. Hypernovas occur in stars with a mass greater than 30 times that of our Sun. Like in a supernova, as the star runs out of fuel it can no longer support itself under its own gravity. It collapses and subsequently explodes, sending out matter in all directions. This releases more energy in seconds than our Sun will in its entire 10 billion-year lifetime.

Hypernovas are incredibly rare. In fact, the rate of hypernovas occurring in the entire Milky Way is estimated to be one every million years, making the observation of the celestial explosions particularly difficult. Twenty-five million light years from Earth in another galaxy astronomers have found what appear to be the remnants of a giant hypernova, providing new information about these huge explosions, but currently there are several theories as to what actually causes them. One school of thought is that a massive star rotating at a very high speed or encased in a powerful magnetic field explodes, ripping apart the inner core. Alternatively, a hypernova could be the result of two stars in a binary system colliding with each other, merging into one gigantic mass and subsequently exploding.

The result is clear, however. A black hole is produced and a huge amount of energy is released in the form of a gamma-ray burst, one of the brightest known events in the universe. In fact, a hypernova releases several million times more light than all of the Milky Way's stars put together.

In this image a massive star (30+ solar masses) collapses to form a rotating black hole emitting twin energetic jets, surrounded by an accretion disc of debris. The star is subsequently torn apart by vigorous winds of newly formed isotope 56Ni blowing off the accretion disc, and shock waves produced as the jets plough through the stellar material. The hypernova, whose luminosity is powered by the radioactive decay of 56Ni, is the result of the explosion of the star.

BIG

© NASA

1. Nova
A nova is the result of a white dwarf star accreting matter from a larger companion star in its vicinity; this in turn leads to a huge explosion.

BIGGER

© ESA

2. Supernova
Once a large star has exhausted its supply of fuel it can no longer support its own mass. It collapses before exploding as a supernova.

BIGGEST

© NASA

3. Hypernova
A hypernova occurs when a hypergiant star collapses in on itself and repeatedly explodes, releasing a great deal of energy in the form of light and heat.

DID YOU KNOW? *A hypernova is about 100 times more powerful than a supernova*

Formation of a hypernova

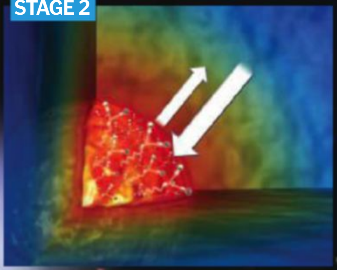
What's going on inside these huge explosions?

STAGE 1

4x © Science Photo Library

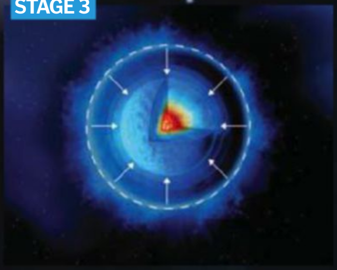
1. Hypergiant
A star greater than 30 times the mass of our Sun can no longer support itself once it has exhausted its fuel.

STAGE 2



2. Super-heated
The core grows super-hot. Once inwards gravitational pressure exceeds outwards radiation pressure the collapse begins.

STAGE 3



3. Collapse
As the collapse continues the extremely high temperature of the compressed core starts a runaway thermonuclear reaction.

STAGE 4

4. Explosion
Eventually the outer parts of the star implode, before a final huge explosion blasts the entire star into space.

When the moon turns red…

Lunar eclipses

What happens when the Earth comes between the moon and the Sun?

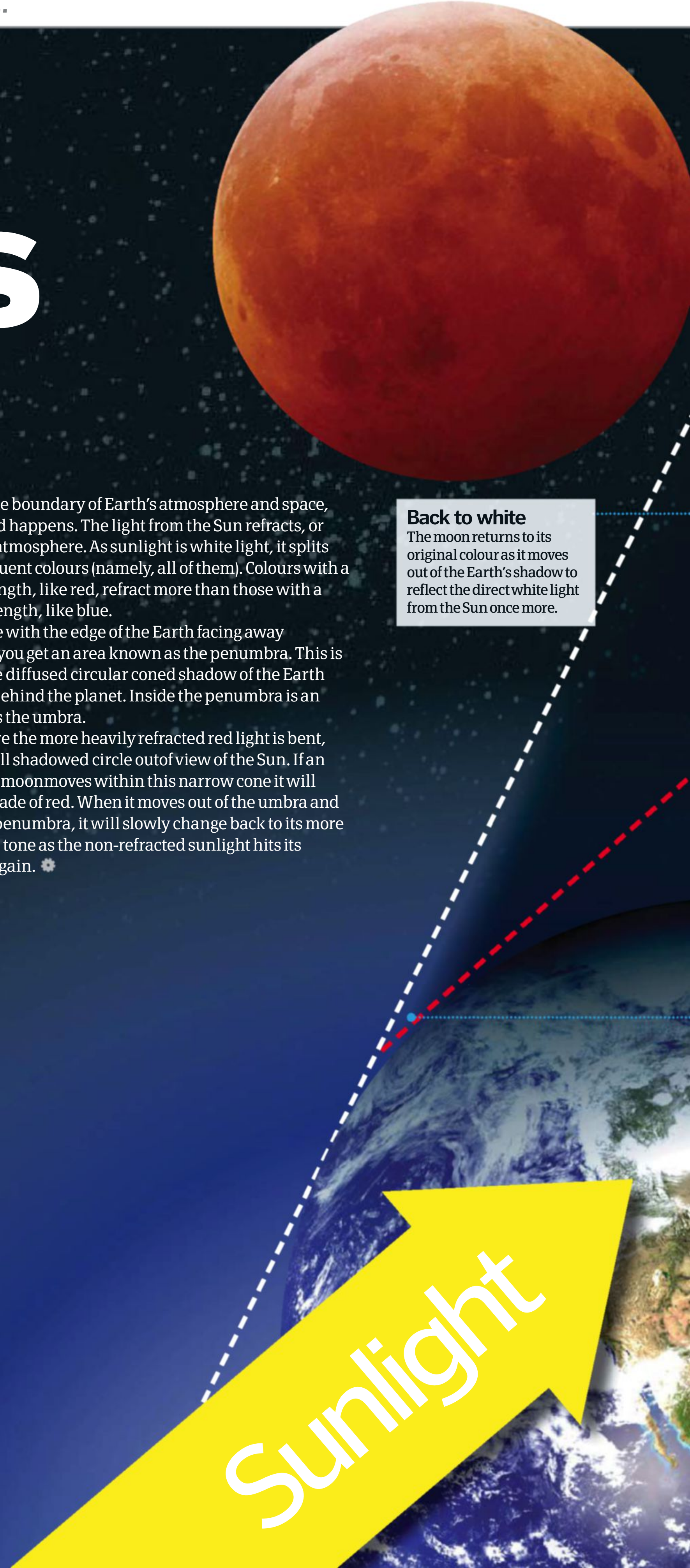
Approximately three times a year, the world experiences a lunar eclipse, when for a brief period of time – ranging from a matter of minutes to hours – the moon appears a dark red colour, despite being entirely out of sight of the Sun. To understand what's going on here we need to get to grips with the motion and phases of the moon as it orbits our planet.

From Earth we only ever see roughly half of the moon. This is because our natural satellite is tidally locked to our planet, so it orbits with the same side facing towards us (although, due to a slight wobble in its orbit, we can actually see about 59 per cent of its surface from the ground). For this reason the moon goes through phases in the night sky, depending on where it is in respect of the Sun. During a full moon the Sun is lighting up the entirety of the half we can see, but when the Sun shines on just the side of the moon we can only see a thin crescent.

As light from the Sun reaches Earth, not all of it hits the surface. Most of it goes straight past our planet into space. However, at the boundary of Earth's atmosphere and space, something odd happens. The light from the Sun refracts, or bends, in our atmosphere. As sunlight is white light, it splits into its constituent colours (namely, all of them). Colours with a longer wavelength, like red, refract more than those with a shorter wavelength, like blue.

Thus, in line with the edge of the Earth facing away from the Sun, you get an area known as the penumbra. This is a slightly more diffused circular coned shadow of the Earth that appears behind the planet. Inside the penumbra is an area known as the umbra.

This is where the more heavily refracted red light is bent, forming a small shadowed circle outof view of the Sun. If an object like the moonmoves within this narrow cone it will turn a deep shade of red. When it moves out of the umbra and back into the penumbra, it will slowly change back to its more familiar white tone as the non-refracted sunlight hits its surface once again.



Predicting an eclipse

How can we be so precise in predicting when an eclipse will occur?

A lunar eclipse only occurs during a full moon, when the moon is directly out of sight of the Sun, but not every full moon is a lunar eclipse. This is due to the position of our natural satellite in relation to the Sun-Earth plane. Although the Earth orbits in a relatively flat plane around the Sun, the moon moves up and down in its orbit in three-dimensional space, about five degrees off this plane. Any point at which it crosses the plane is called a node. When a node and full moon coincide this is when we can observe a lunar eclipse, as the moon will be completely obscured from the Sun by the Earth.

It takes 27.2 days for the moon to move from node to node, but 29.5 days for it to go through its full moon phases, so lunar eclipses will occur at a rate of approximately three a year across the globe. The moon's cycle of dancing between nodes and changing to a full moon is known as the Saros cycle and takes 6,585 days to complete, allowing lunar eclipses to be predicted long into the future.

There is absolutely no danger in observing a lunar eclipse. The light reflected from the moon poses no threat to your eyesight, unlike solar eclipses, which can be dangerous to view with the naked eye.

DID YOU KNOW?

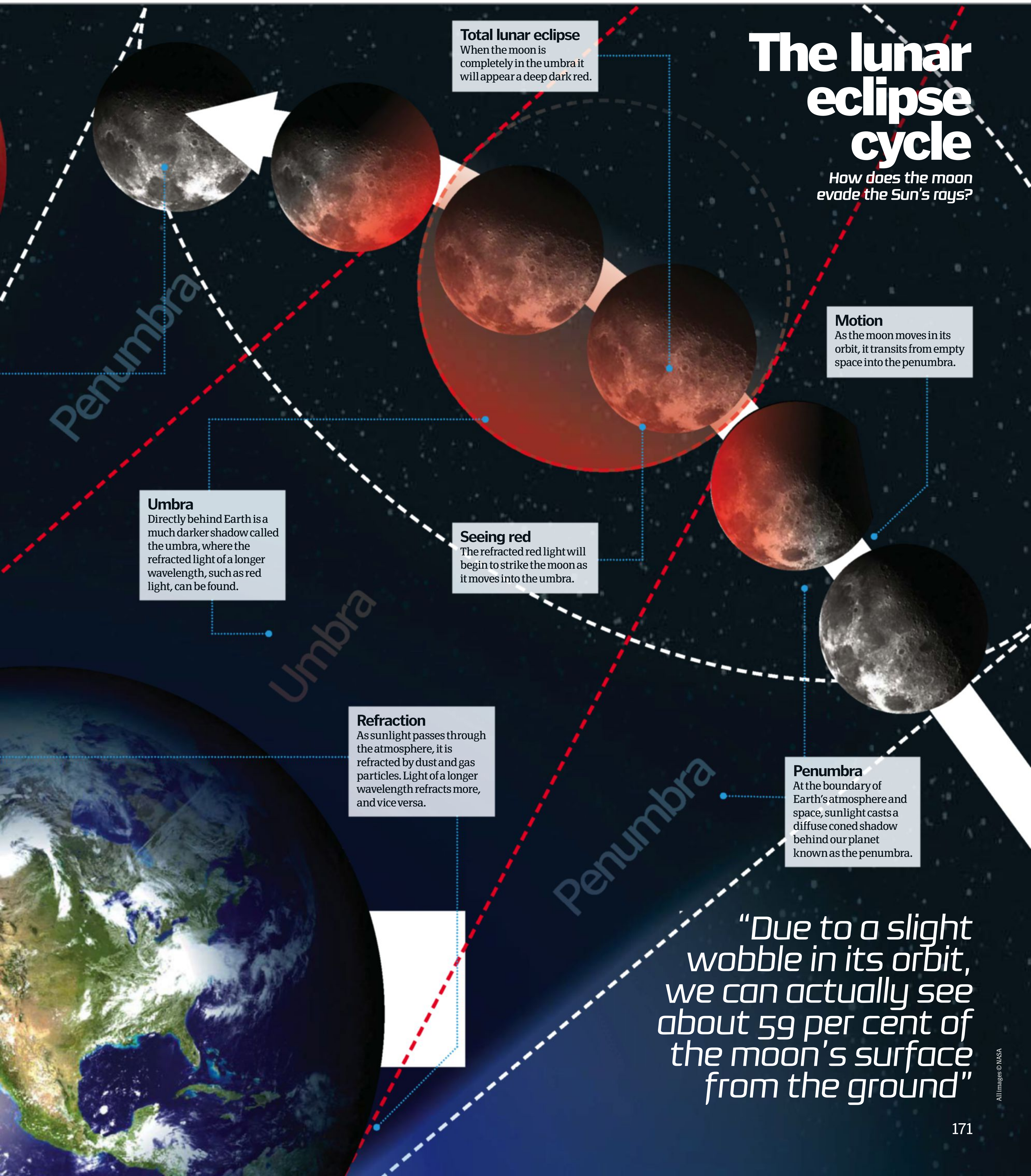
Angry deity

In ancient times, lunar eclipses were considered a bad omen from the deities and largely misunderstood, as well as being used as markers in celestial calendars. In 1504 Christopher Columbus, who knew about the lunar phases, tricked native Jamaicans by telling them that his god would turn the moon red until they had gathered him food and supplies.

DID YOU KNOW? *A lunar eclipse can be viewed anywhere on Earth where it is night, unlike a solar eclipse*

The lunar eclipse cycle

How does the moon evade the Sun's rays?



Total lunar eclipse

When the moon is completely in the umbra it will appear a deep dark red.

Motion

As the moon moves in its orbit, it transits from empty space into the penumbra.

Umbra

Directly behind Earth is a much darker shadow called the umbra, where the refracted light of a longer wavelength, such as red light, can be found.

Seeing red

The refracted red light will begin to strike the moon as it moves into the umbra.

Refraction

As sunlight passes through the atmosphere, it is refracted by dust and gas particles. Light of a longer wavelength refracts more, and vice versa.

Penumbra

At the boundary of Earth's atmosphere and space, sunlight casts a diffuse coned shadow behind our planet known as the penumbra.

"Due to a slight wobble in its orbit, we can actually see about 59 per cent of the moon's surface from the ground"

European Extremely Large Telescope

How will this record-breaking observatory hunt for Earth-like planets?

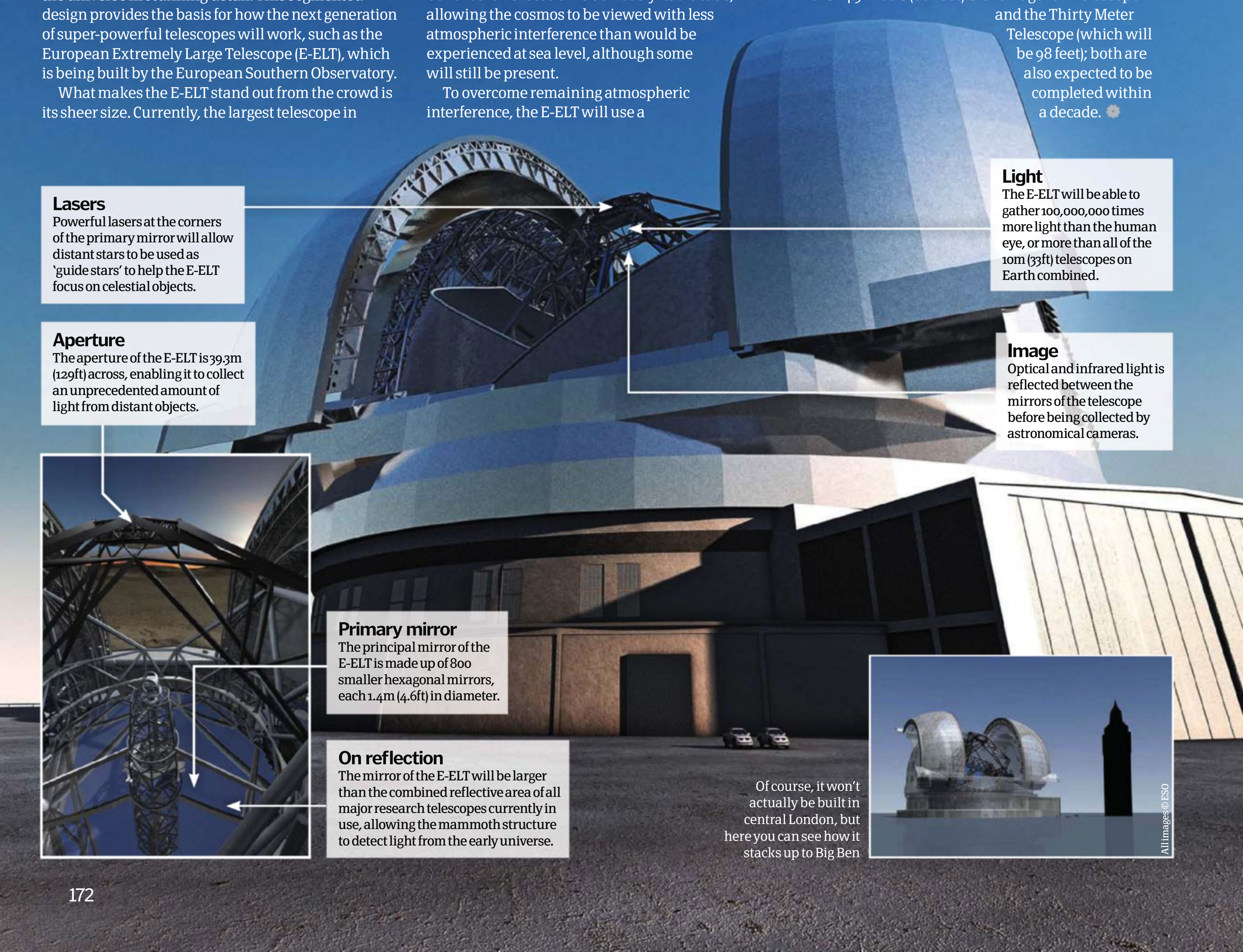
Since its invention over 400 years ago the humble telescope has come on leaps and bounds. In the early-20th century astronomers relied on old single or twin-mirror methods to produce images of distant galaxies and stars, but as the size of telescopes increased the quality of imagery reduced. It wasn't until the arrival of the Keck Observatories in Hawaii in the Eighties and Nineties, using 36 smaller mirror segments stitched together like a honeycomb, that telescopes were really able to view distant corners of the universe in stunning detail. This segmented design provides the basis for how the next generation of super-powerful telescopes will work, such as the European Extremely Large Telescope (E-ELT), which is being built by the European Southern Observatory.

What makes the E-ELT stand out from the crowd is its sheer size. Currently, the largest telescope in operation on Earth is the Large Binocular Telescope in Arizona, USA, sporting an aperture that measures a 'measly' 11.9 metres (39 feet) in diameter. The aperture of the E-ELT comes in at a mammoth 39.3 metres (129 feet), about half the size of a football pitch.

The telescope, expected to be finished within a decade, will be built on Cerro Armazones, a 3,000-metre (9,800-foot) mountain located in Chile's Atacama Desert where many other telescopes, including the recently activated Atacama Large Millimeter/submillimeter Array (ALMA), reside. The benefit of this location is obviously its altitude, allowing the cosmos to be viewed with less atmospheric interference than would be experienced at sea level, although some will still be present.

To overcome remaining atmospheric interference, the E-ELT will use a technology known as adaptive optics. Disturbances in the atmosphere can be accounted for by measuring the air within the telescope's view. Tiny magnets move its 800 segmented mirrors about 2,000 times a second to adjust the view to avoid any turbulence.

The primary goal of the E-ELT is to observe Earth-like planets in greater detail than ever before, but it will also be able to see much fainter objects – possibly even the primordial stars that formed soon after the Big Bang. Apart from the E-ELT there are two other extremely large telescopes under construction: the 24.5-metre (80-foot) Giant Magellan Telescope and the Thirty Meter Telescope (which will be 98 feet); both are also expected to be completed within a decade.



Of course, it won't actually be built in central London, but here you can see how it stacks up to Big Ben

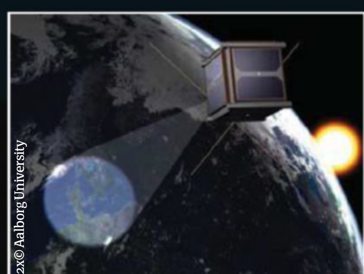
CubeSats

How these tiny satellites produce lots of useful data from space

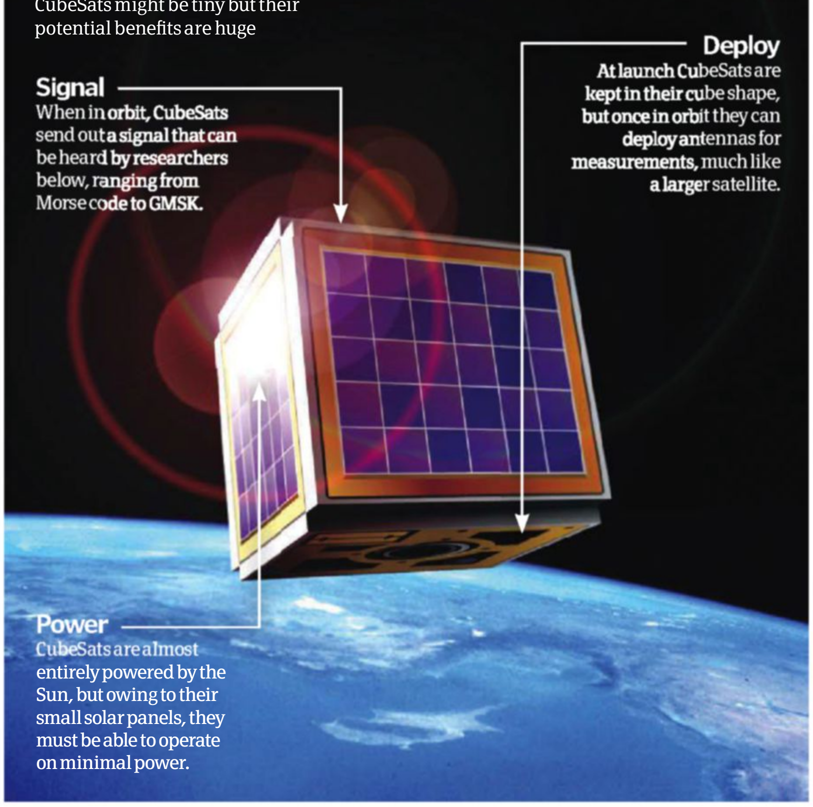
CubeSats are tiny, miniaturised satellites sent into Earth orbit, typically by universities, for research and other purposes. They tend to measure no more than ten centimetres (four inches) along each side, and weigh at most one kilogram (2.2 pounds). The ten by ten configuration is known as a 1U CubeSat, while 2U and 3U models have also been launched, measuring 20 and 30 centimetres (7.9 and 11.8 inches) along their longest edge, respectively. The devices might be small but they are incredibly useful, providing data in specific areas comparable with larger national organisations. Their tiny size means that hitching a ride on a rocket is affordable for universities, coming in at under £50,000 ($80,000).

CubeSats carry no propellant, but are instead placed in an orbital band by the rocket they launch upon. There are plenty of uses for CubeSats, with some measuring the aurora borealis at Earth and others detecting cosmic dust. Owing to their scale, several can be launched alongside a larger payload as well. For example, in December 2010, several CubeSats were deployed by SpaceX's Falcon 9 rocket on one of its test flights.


© Svobodat


2x© Aalborg University

CubeSats might be tiny but their potential benefits are huge



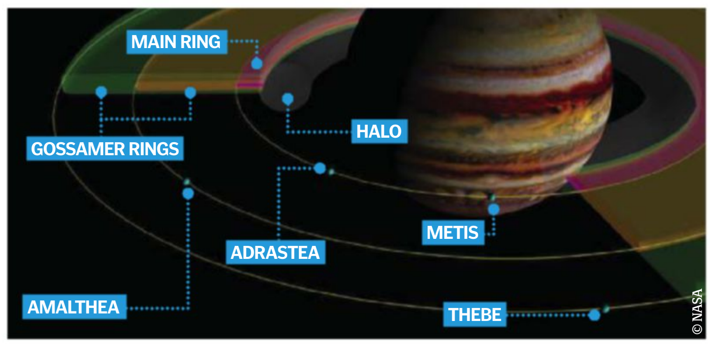
Rings of Jupiter

What is encircling this gas giant?

Jupiter's ring system is so faint it was more than 350 years after the planet was first observed that it was found to have any rings at all. They are believed to have been created largely from meteoritic impacts on some of Jupiter's many moons and they're composed mostly of dust particles, as opposed to the icy, rocky debris that encircles Saturn.

The main ring begins almost 130,000 kilometres (81,000 miles) above the centre of the planet and extends outwards a further 7,000 kilometres (4,350 miles). Inside the main ring are two of Jupiter's 64 known moons, the small Adrastea and Metis, thought to be the primary culprits of the majority of the dust present in the main ring.

Between the main ring and the cloud top of Jupiter is a region known as the halo, a faint collection of material 10,000 kilometres (6,200 miles) wide. Outside the main ring is an even fainter series of dust known as the gossamer rings, held in position by the gravity of the nearby moons Amalthea and Thebe.



© NASA

Star clusters

What causes these stellar parties?

A star cluster is a group of stars brought together over millions or billions of years that have grown gravitationally bound to one another. The two known types are globular and open clusters. One of the most fascinating things about them is that all of the stars in such a group are centred around the same gravitational point, despite also often being inside a galaxy.

Open clusters are much smaller than their globular brothers, the former containing just a dozen to a few hundred stars, and the latter potentially encompassing hundreds of thousands. Globular clusters tend to be more uniform too, with the stars forming a sphere around a common central point, while in an open cluster stars are more scattered owing to the weaker gravity. Globular clusters typically have older stars that have been bound for millions of years, whereas open clusters are composed of newer stars that may come and go over time.


© NASA, ESA

Planets

Today, we know of several hundred planets throughout the universe, from fiery rocky worlds to gas giants bigger than Jupiter, but there are many billions more just waiting to be discovered. What do we know so far, and what might we find in the future? Read on to find out

The definition and classification of planets has been the cause of debate for many years. You may recall one controversy in 2006 when Pluto, previously the ninth planet of the solar system, was stripped of its 'true' planet status, and demoted to a dwarf planet, sending the astronomical and scientific communities into an uproar. But just why was this reclassification necessary, and what exactly is a planet? You're about to find out.

The word 'planet' derives from the Greek word 'planetes', or 'wanderer', named because of their apparent motion across the sky relative to the stars. A planet is a celestial body that orbits a parent star, and is larger than an asteroid but smaller than a star. Planets are differentiated from stars by not being able to radiate energy through nuclear fusion, instead 'powered' by a core composed of metal and other elements.

There are a number of boxes a body must tick in order to be classified as a planet. For starters, its mass and gravity must be large enough to have squashed it into a sphere through its own rotation and interaction with other bodies. Asteroids and comets do not possess enough mass for this to occur, and thus they are often seen to have irregular shapes, while planets are almost spherical in appearance, with a slight bulge around their equator due to their rotation. It is loosely agreed that for this to occur, a planet must be bigger than the largest known asteroid, Ceres, which is roughly 1,000 kilometres (600 miles) in diameter (although Ceres has been reclassified as a dwarf planet).

Next, a body must be in orbit around a parent star to be considered a planet, and must itself not be a satellite of another planet. For example, while the moon can be said to be in orbit around both the Sun and the Earth, its motion is largely determined and regulated by the latter. Thus, it is not a planet.

Head to Head
PLANET HUNTERS

© NASA

1. Kepler
NASA's Kepler telescope, which is in orbit around Earth, has found over 1,200 planetary candidates to date since its launch in 2009.

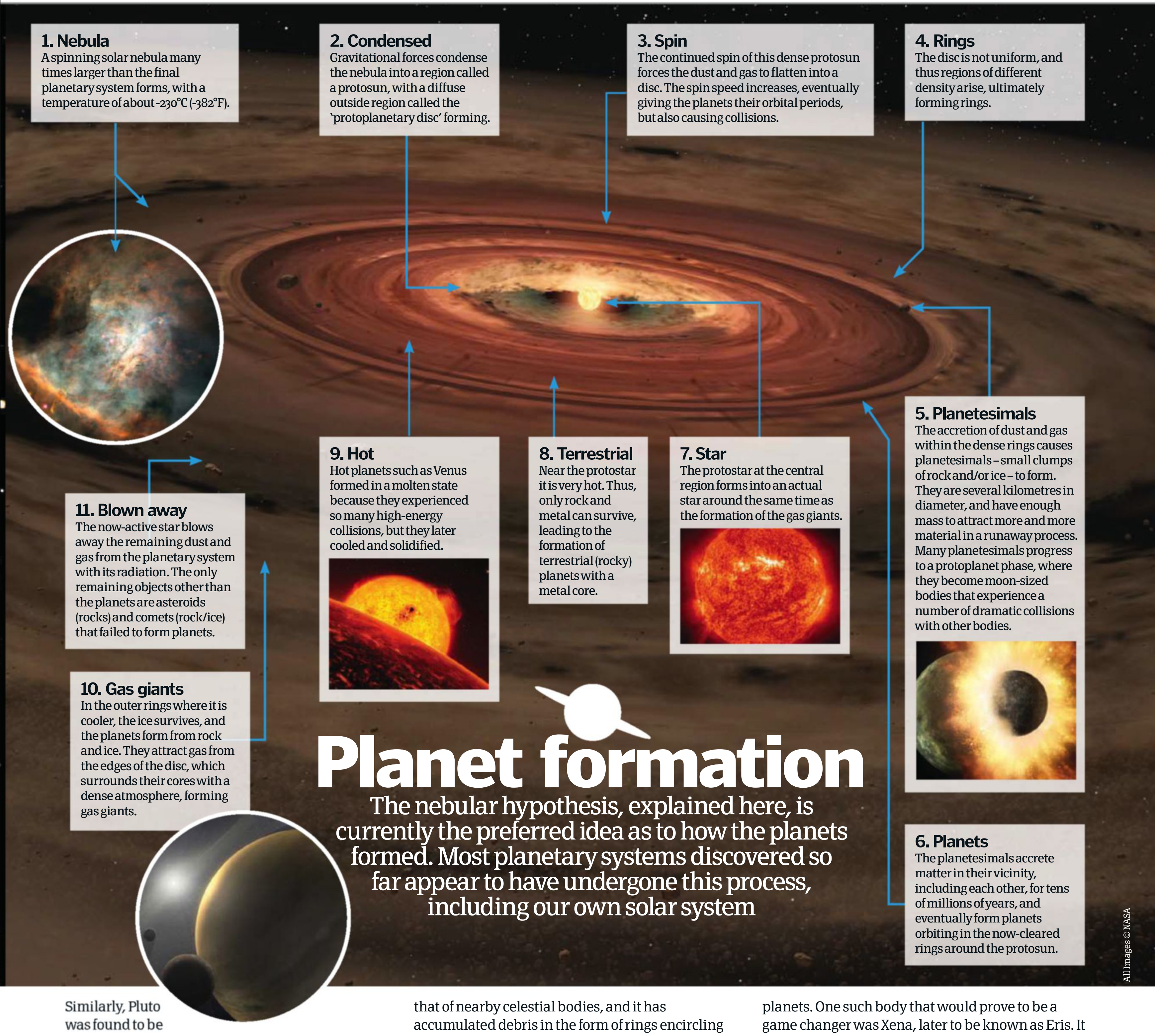
© CNES/D. Ducros

2. COROT
The French Space Agency's COROT mission has confirmed the discovery of dozens of planets, and found hundreds more candidates since the mission began in 2007.

© Eurockot Launch Services

3. MOST
Canada's only space telescope, MOST is the first spacecraft to deal in asteroseismology, observing variations in stars to find planets.

DID YOU KNOW? As of September 2011, over 600 celestial bodies have been found, classed and verified as planets



Planet formation

The nebular hypothesis, explained here, is currently the preferred idea as to how the planets formed. Most planetary systems discovered so far appear to have undergone this process, including our own solar system

1. Nebula
A spinning solar nebula many times larger than the final planetary system forms, with a temperature of about -230°C (-382°F).

2. Condensed
Gravitational forces condense the nebula into a region called a protosun, with a diffuse outside region called the 'protoplanetary disc' forming.

3. Spin
The continued spin of this dense protosun forces the dust and gas to flatten into a disc. The spin speed increases, eventually giving the planets their orbital periods, but also causing collisions.

4. Rings
The disc is not uniform, and thus regions of different density arise, ultimately forming rings.

5. Planetesimals
The accretion of dust and gas within the dense rings causes planetesimals – small clumps of rock and/or ice – to form. They are several kilometres in diameter, and have enough mass to attract more and more material in a runaway process. Many planetesimals progress to a protoplanet phase, where they become moon-sized bodies that experience a number of dramatic collisions with other bodies.

6. Planets
The planetesimals accrete matter in their vicinity, including each other, for tens of millions of years, and eventually form planets orbiting in the now-cleared rings around the protosun.

7. Star
The protostar at the central region forms into an actual star around the same time as the formation of the gas giants.

8. Terrestrial
Near the protostar it is very hot. Thus, only rock and metal can survive, leading to the formation of terrestrial (rocky) planets with a metal core.

9. Hot
Hot planets such as Venus formed in a molten state because they experienced so many high-energy collisions, but they later cooled and solidified.

10. Gas giants
In the outer rings where it is cooler, the ice survives, and the planets form from rock and ice. They attract gas from the edges of the disc, which surrounds their cores with a dense atmosphere, forming gas giants.

11. Blown away
The now-active star blows away the remaining dust and gas from the planetary system with its radiation. The only remaining objects other than the planets are asteroids (rocks) and comets (rock/ice) that failed to form planets.

Similarly, Pluto was found to be directly under the influence of Neptune. In fact, Neptune accounts for more than two thirds of Pluto's motion, orbit and rotation.

Finally, a planet must have cleared or accumulated all debris in its vicinity, either causing it to form a moon through its gravitational forces, or adding it to its own structure. In other words, the planet must 'dominate' its orbital zone. For example, Jupiter has its own Jovian system, consisting of moons and asteroids in its orbital band around the Sun. Its mass is many thousand times more than that of nearby celestial bodies, and it has accumulated debris in the form of rings encircling the planet.

It is on this characteristic that Pluto predominantly failed. It orbits in and around the Kuiper asteroid belt, but has not cleared or accumulated debris in its vicinity, namely other asteroids. Thus, it is now classed as a dwarf planet, or 'plutoid', the latter denoting a dwarf planet that is beyond the orbit of Neptune.

Another reason for the reclassification of Pluto was that many bodies of a similar size were found in the solar system, but they had not been considered planets. One such body that would prove to be a game changer was Xena, later to be known as Eris. It was larger than Pluto, and was briefly regarded as the tenth planet of the solar system before the International Astronomical Union (IAU) changed its classification of a planet in 2006 to include a new category: dwarf planets.

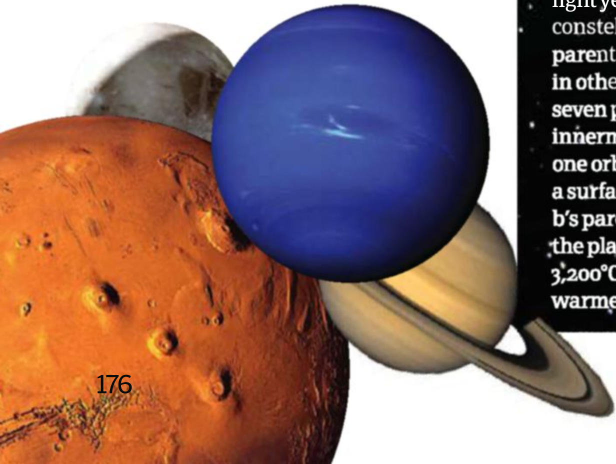
To be a dwarf planet, an object must meet two of the three conditions of being a regular planet. It must be in orbit around a star and it must be spherical in shape. However, a dwarf planet has not cleared its neighbourhood, and it also cannot be the moon of another planet. For example, Charon, which ▶

has a body more than half the size of Pluto, would be classified as a dwarf planet if it were not in orbit of Pluto, and thus is regarded as a moon. So far, no dwarf planets have been found outside the solar system, as they are too small for modern telescopes to find. The smallest extrasolar planet discovered to date, Kepler-10 b, is roughly 1.4 times the size of Earth.

Finding planets outside the solar system is no easy feat. Indeed, the first was not discovered until the Nineties. Extrasolar planets, as they are known, are too distant to be directly observed by telescopes on Earth or in space, so instead the relative luminosity of a star is measured to determine if another body, such as a planet, is in orbit. If the observed luminosity of a distant star regularly dims, then the motion of a planet across its plane can be measured. In addition, noting the gravitational effects a planet has on its host star can also enable astronomers to determine many of the planet's characteristics, including its rotation, composition, temperature and orbital distance.

Planet hunting is a very new area of astronomy that is still in its infancy. There are billions of worlds just waiting to be found, and it's likely that some will be unlike anything we've seen before, such as the planet found 4,000 light years away in August 2011 composed entirely of carbon, resembling a giant diamond. As Earth and space telescopes get more and more powerful, it's likely that we'll find other fascinating planets like this that break our preconceptions about the structure, size and appearance of planets.

"Planet hunting is a very new area of astronomy that is still in its infancy"

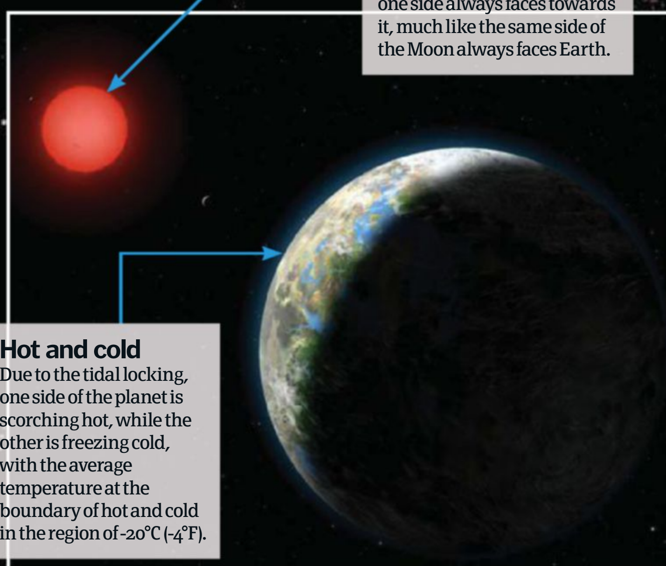


Amazing planets

Hottest, coldest, largest, oldest… We take a look at the greatest planets of the universe discovered so far

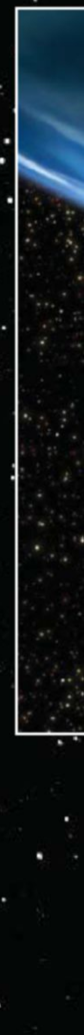
Most Earth-like
Gliese 581 g

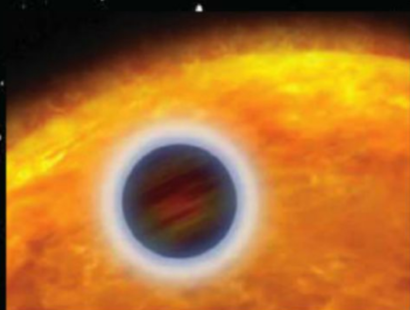
Informally known as Zarmina, Gliese 581 g has three to four times the mass of Earth, is no more than 1.4 times the size, and orbits its host red dwarf star, Gliese 581, in just under 37 days. It is located 20 light years from Earth in the Libra constellation. The honour of most Earth-like planet was previously held by Gliese 581 d, located in the same planetary system as Gliese 581 g, until the latter was discovered in 2010. Observations indicate that Zarmina is a rocky planet with enough mass to hold on to an atmosphere, in addition to possessing a solid surface. It is located within the habitable zone of its host star – the region around any star where a planet could possess liquid water, and possibly life.



Locked
Gliese 581 g is tidally locked to its host star, which means that one side always faces towards it, much like the same side of the Moon always faces Earth.

Hot and cold
Due to the tidal locking, one side of the planet is scorching hot, while the other is freezing cold, with the average temperature at the boundary of hot and cold in the region of -20°C (-4°F).





Hottest planet
WASP-33 b

This planet, 1.4 times the size of Jupiter and almost 4.5 times its mass, is located 380 light years from Earth in the Andromeda constellation. It is 35 times closer to its parent star than the Earth is to the Sun, or in other terms it orbits at a distance just seven per cent that of our solar system's innermost planet, Mercury, and completes one orbit every 29 hours. While the Sun has a surface temperature of 5,600°C, WASP-33 b's parent star is a scorching 7,160°C, giving the planet a blistering temperature of 3,200°C. That's seven times hotter than the warmest planet in our solar system, Venus.

Coldest planet Eris

The coldest planet that we currently know of in the universe is the dwarf planet Eris (known as Xena until September 2006), located in the Kuiper asteroid belt on the outer edges of our solar system. Eris is roughly 27 per cent bigger than Pluto, and is the farthest planet found to be orbiting the Sun, three times further than Pluto at a distance of 16 billion kilometres (10 billion miles). However, in its 560-year orbit, it moves between 38 and 97 AU, which directly affects its surface temperature. Eris is currently at its furthest distance from the Sun, and thus also its coldest temperature – as low as -250°C (-418°F). At this temperature, its atmosphere is frozen solid.

In 280 years, Eris will be at its closest point to the Sun, when its temperature will rise to a 'mild' -218°C (-360°F).

While Eris is the coldest known planet, it's likely that there are colder planets elsewhere in the universe. Some scientists predict that there are rogue planets unattached to stars wandering through the universe. If this is true, then these could be similar in temperature to the universe itself, about -270°C (2.7 Kelvin).

DID YOU KNOW?

© National Science Foundation

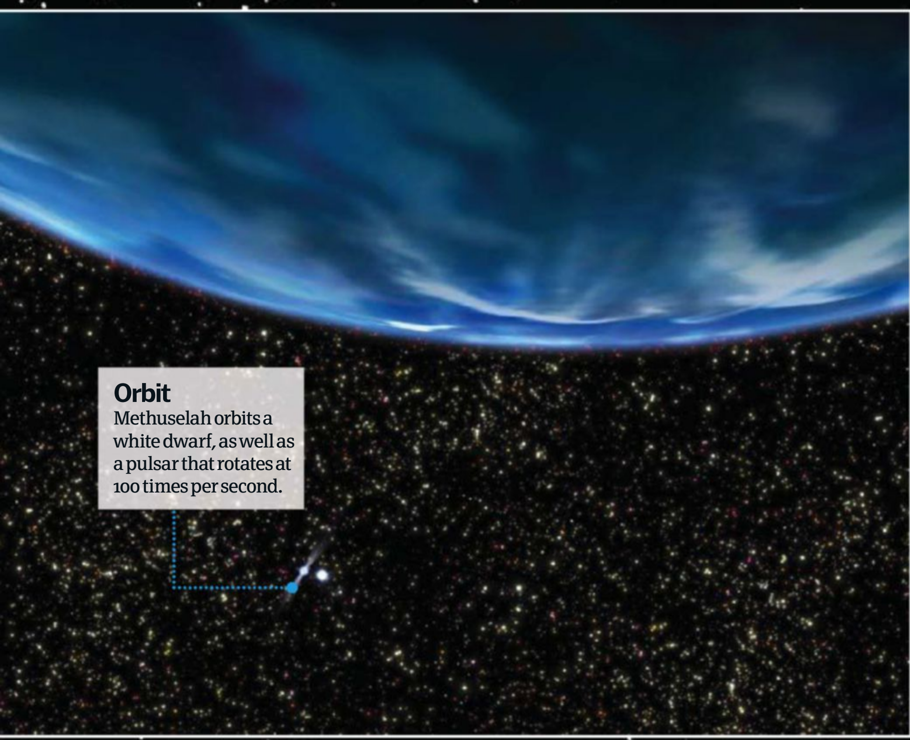
What's in a name?

Struggling to remember the multitude of seemingly weird letters and numbers designating a planet? The first part (Gliese 581, for example) is the name of that planet's host star, and the latter letter (such as 'g') denotes the order of the planet in terms of distance away from its star.

DID YOU KNOW? One AU (astronomical unit) is the distance from the Sun to the Earth; roughly 150 million kilometres.

Oldest planet PSR B1620-26 b

You might want to remember this ancient planet by one of its unofficial names, either Methuselah or the Genesis planet. At 12.7 billion years old, nearly three times the age of Earth, Methuselah is the oldest planet yet discovered in the universe, and suggests that planets formed very soon after the Big Bang 13.7 billion years ago. This bodes well for planet hunters, as if planets formed this early then there could be millions or even billions more spread throughout the universe. Methuselah orbits two stars, one a pulsar and the other a white dwarf, known as a circumbinary orbit. It's 12,400 light years from Earth in the Scorpius constellation and has a mass 2.5 times that of Jupiter.

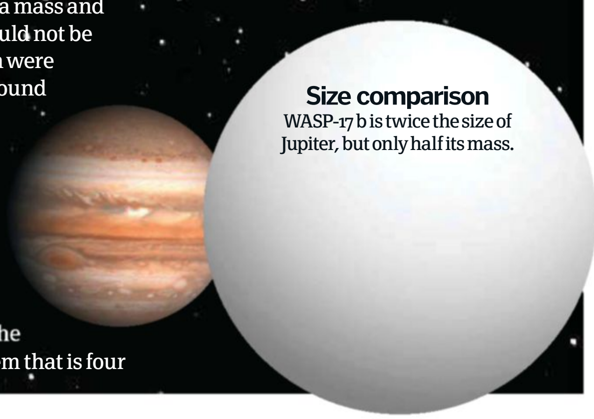


Orbit
Methuselah orbits a white dwarf, as well as a pulsar that rotates at 100 times per second.

Biggest planet WASP-17 b

Located in the Scorpius constellation 1,000 light years from Earth, WASP-17 b is the largest planet discovered in the universe thus far. It's twice the size of Jupiter, but only half its mass, making it 'fluffy' in appearance and structure. Currently, it is believed that the larger a planet is above the size of Jupiter, the lower its mass will become. This is because a planet with both a mass and size greater than Jupiter would not be able to support itself. If both were significantly greater – by around 15 times – the body would likely form a star instead of a planet.

Two American astronomers, John Matese and Daniel Whitmire of the University of Louisiana at Lafayette, assert that there is a planet hidden in the Oort Cloud of our solar system that is four times the mass of Jupiter, provisionally named Tyche. Although it has not been observed, Matese and Whitmire point to the highly elliptical orbits of comets that suggest they are influenced by another body in the solar system, namely the hidden theoretical gas giant Tyche. Many astronomers remain sceptical of this view, however.



Size comparison
WASP-17 b is twice the size of Jupiter, but only half its mass.

TYPES OF PLANET

The study of extrasolar planets is a very new area of astronomy, one that is barely 20 years old. As such, the classification of planets is still in its early stages, and for now, extrasolar planets are categorised in a similar manner to the planets of our own solar system; namely, they are defined as either terrestrial or gas giant planets, while dwarf planets are limited to our own solar system. It is likely that future planetary discoveries may require further reclassification of the planets into more clearly defined categories, such as mostly silicon, carbon or water worlds.

Although a dwarf planet is not technically a planet, we include them here as their formation and structure are largely similar to 'true' planets.

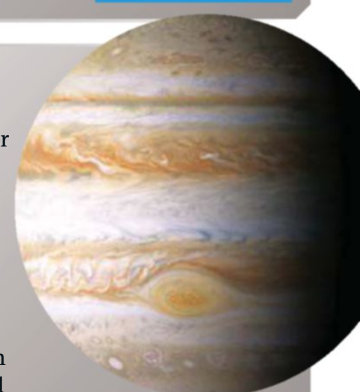
Terrestrial

Terrestrial planets like Earth, Mars and Gliese 581 g are rocky planets with metal cores and high densities. They have solid surfaces and can vary in temperature, although they tend to be warmer than gas giants. They are smaller than gas giants due to their high densities, and have slower rotation periods. In addition, their smaller size means they are less likely to have moons than gas giants. Indeed, in our solar system, only Earth (one) and Mars (two) have moons; Venus and Mercury have more.

Example: Earth

Gas giant

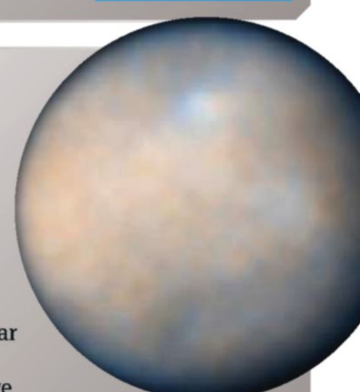
These large, gaseous planets form further out from their parent stars than terrestrial planets. At a further distance from their orbiting star, they are able to accrete more matter in their formation, giving them a large size and mass. For example, Jupiter is 11 times larger than Earth, and has a volume 1,000 times greater. They have a low density, but high speed of rotation, and are often encircled by rings because they have gathered a lot of material.



Example: Jupiter

Dwarf planet

These are larger than asteroids but smaller than 'true' planets. The difference between an asteroid and a dwarf planet comes down to its shape. Bodies smaller than a few kilometres – like asteroids and comets – do not have sufficient mass to pull themselves into a spherical shape, instead forming irregular 'potato' shapes. To be a dwarf planet, a body must have sufficient mass to achieve hydrostatic equilibrium, when it will become spherical.



Example: Ceres

Inflatable space stations

Could this new type of module revolutionise space living?

Inflatable space modules are a proposed way to set up sizable space habitats in Earth orbit at a much lower cost than currently possible. Unlike the existing modules on the International Space Station (ISS), which must be constructed and launched in their finished state, inflatable modules would be folded up on the rocket. Once they reach orbit they would be pumped full of a gas, such as nitrogen, to expand to their full size. It is estimated that just one inflatable module packed into a rocket could one day have the potential to expand to the size of the entire ISS, roughly equivalent to an American football field, which is about 100 metres (328 feet) in width.

At the forefront of inflatable space technology is Bigelow Aerospace. This company has launched and tested two modules in space – Genesis I and II (in 2006 and 2007, respectively) – which have proved that inflatable modules are just as reliable, if not more so, than their metallic counterparts. In one test, Bigelow found that its Kevlar fabric modules were more resilient to micrometeoroid impacts than the casings of the ISS modules. Bigelow's next inflatable spacecraft will be the Sundancer module, due to launch by 2014 at the earliest. It will be the first inflatable module in orbit around Earth capable of supporting humans on board.

DID YOU KNOW?

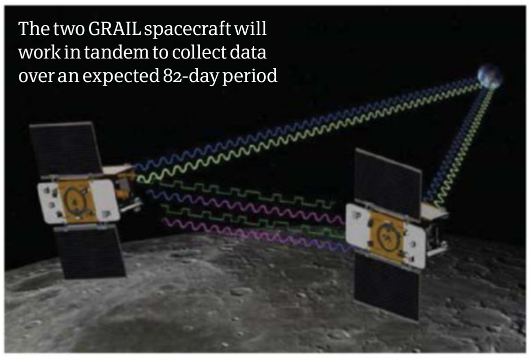
Voyager shock

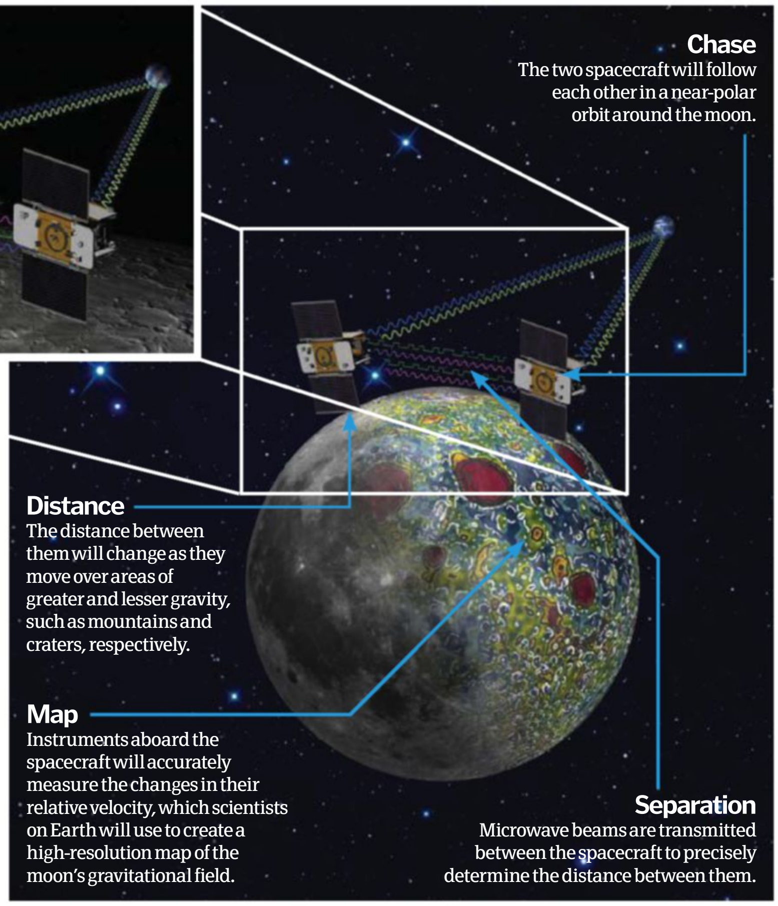
NASA's Voyager probes are currently at the edge of the solar system. Here, they have observed a significant decrease in the solar wind, suggesting that they have found the Sun's bow shock at the boundary of interstellar space. It is roughly 230 times further from the Sun than Earth.

DID YOU KNOW? *At the end of their mission the GRAIL probes will be crashed into the surface of the moon*

GRAIL probes

The spacecraft that will study the moon in prodigious detail


The two GRAIL spacecraft will work in tandem to collect data over an expected 82-day period

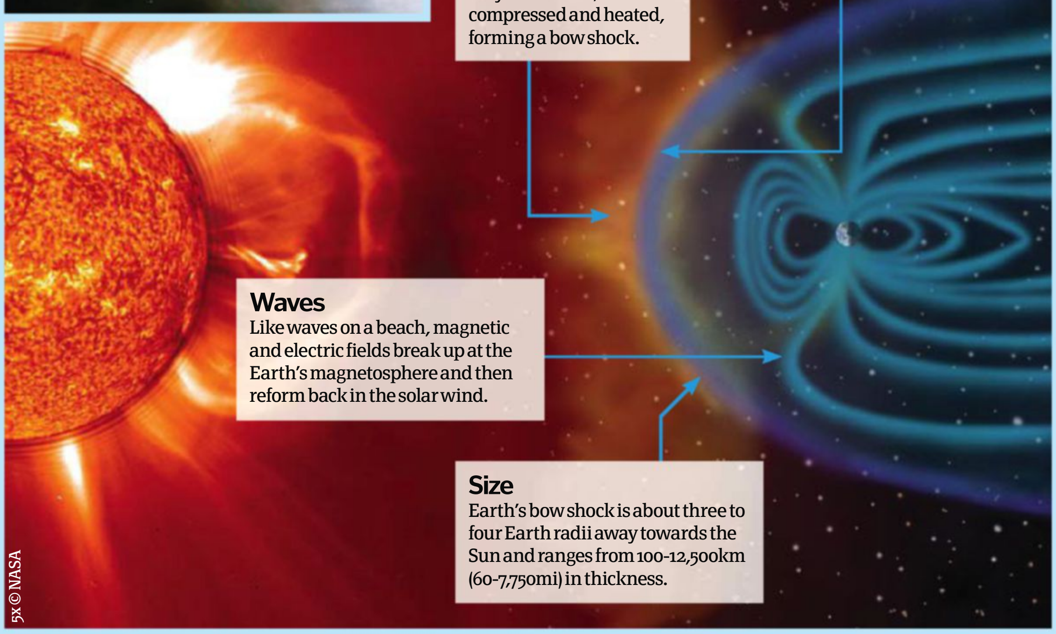


NASA's Gravity Recovery and Interior Laboratory (GRAIL) mission is studying the moon's gravity in unprecedented detail, using two spacecraft 50 kilometres (30 miles) above its surface. Each spacecraft – GRAIL-A and GRAIL-B – weighs 202 kilograms (445 pounds) and is the size of a washing machine. The two probes will chase each other around the lunar surface in a near-polar orbit. On board each is a lunar gravity ranging system (LGRS), which monitors the distance between the spacecraft down to a few microns (the diameter of a red blood cell), allowing the influence of the moon's gravity on the spacecraft to be accurately recorded. A similar experiment called GRACE (Gravity Recovery and Climate Experiment) has been performing a near-identical manoeuvre to map the gravity of the Earth since 2002.

After launching in September 2011 it took the GRAIL spacecraft almost four months to reach the moon. The journey normally would only take around three days, but NASA opted to use a lengthier, slower path to eradicate the need for a large amount of fuel (and thus a higher cost) on board the spacecraft. After entering the moon's orbit on New Year's Day the probes have been merging their orbits relative to each other. They began mapping the moon's gravity from March through to May.

What are bow shocks?


The red giant star Mira A produces a bow shock 13 light years in length



What happens when the solar wind hits Earth?

A bow shock is the point at which groups of particles from a source, such as the solar wind, encounter a new medium, such as the magnetic field of a planet. An example would be the point at which the Sun's solar wind abruptly drops as it hits the Earth's magnetosphere. Bow shocks are apparent at every planet in the solar system, but also in other places – for instance, at the edge of the solar system, where the solar wind reaches interstellar space (see 'Voyager shock' above).

So, what exactly is a bow shock? It's basically the point at which particles travelling through space experience an abrupt change in the medium they are passing through, resulting in a sudden decrease in velocity – like the difference between a marble falling through water compared to a jar of treacle. As the solar wind traverses the solar system it is generally unhindered, but when it hits a new medium – such as Earth's magnetic field – it encounters considerable resistance and forms a bow shock as a result.

Automated transfer vehicles

How do these European resupply craft keep the ISS fully stocked?


Each ATV is capable of carrying 6.6 tons of cargo to the ISS

The European Space Agency's automated transfer vehicles (ATVs) are unmanned spacecraft designed to take cargo and supplies to the International Space Station (ISS), before detaching and burning up in Earth's atmosphere. They are imperative in maintaining a human presence on the ISS, bringing various life essentials to the crew such as water, food and oxygen, in addition to new equipment and tools for conducting experiments and general maintenance of the station.

The first ATV to fly was the Jules Verne ATV-1 in 2008; it was named after the famous 19th-century French author who wrote *Around The World In 80 Days*. This was followed by the (astronomer) Johannes Kepler ATV-2 in February 2011, and will be succeeded by the (physicists) Edoardo Amaldi and Albert Einstein ATVs in 2012 and 2013, respectively.

The ATV-1 mission differed somewhat from the subsequent ones as it was the first of its kind attempted by the ESA and thus various additional procedures were carried out, such as testing the vehicle's ability to manoeuvre in close proximity to the ISS for several days to prevent it damaging the station when docking. However, for the most part, all ATV missions are and will be the same.

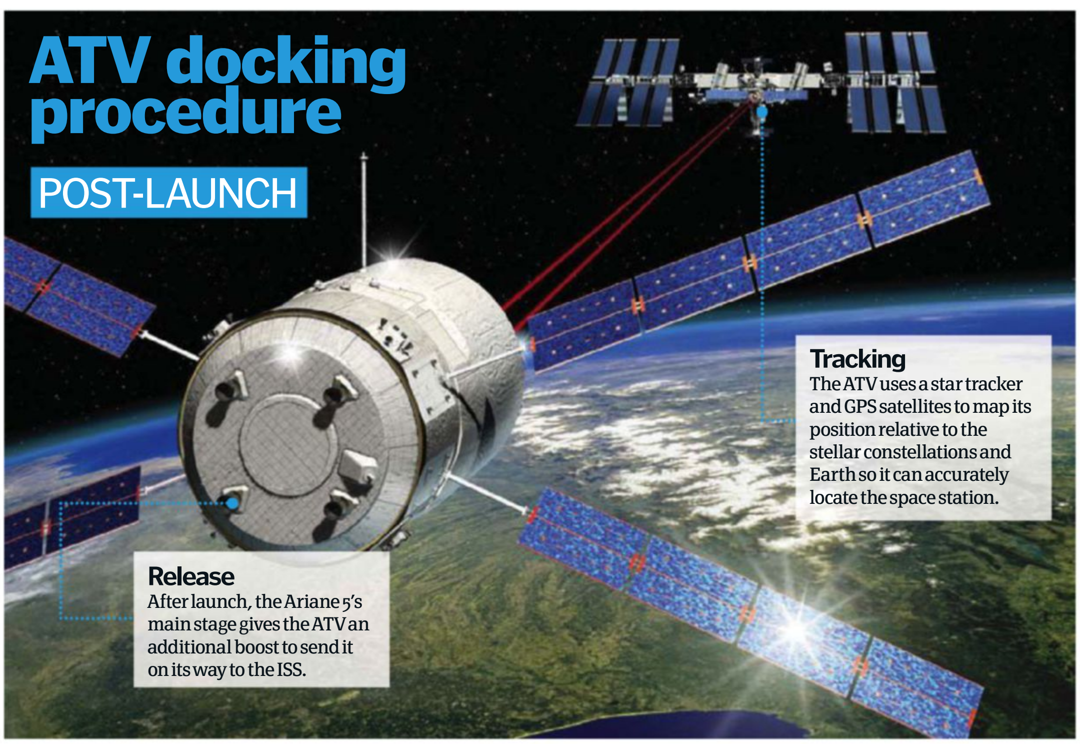
ATVs are launched into space atop the ESA's Ariane 5 heavy-lift rocket. Just over an hour after launch the rocket points the ATV in the direction of the ISS and gives it a boost to send it on its way, with journey time to the station after separation from the rocket taking about ten days. The ATV is multifunctional, meaning that it is a fully automatic vehicle that also possesses the necessary human safety requirements to be boarded by astronauts when attached to the ISS. Approximately 60 per cent of the entire volume of the ATV is made up of the integrated cargo carrier (ICC). This attaches to the service module, which propels and manoeuvres the vehicle. The ICC can transport 6.6 tons of dry and fluid cargo to the ISS, the former being pieces of equipment and personal effects and the latter being refuelling propellant and water for the station.

As well as taking supplies, ATVs also push the ISS into a higher orbit, as over time it is pulled towards Earth by atmospheric drag. To raise the ISS, an ATV uses about four tons of its own fuel over 10-45 days to slowly nudge the station higher.

The final role of an ATV is to act as a waste-disposal unit. When all the useful cargo has been taken off the vehicle, it is filled with superfluous matter from the ISS until no more can be squeezed in. At this point the ATV undocks from the station and is sent to burn up in the atmosphere.

ATV docking procedure

POST-LAUNCH



Tracking
The ATV uses a star tracker and GPS satellites to map its position relative to the stellar constellations and Earth so it can accurately locate the space station.

Release
After launch, the Ariane 5's main stage gives the ATV an additional boost to send it on its way to the ISS.

APPROACH

Locking on
When it's 300m (984ft) from the ISS, the ATV switches to a high-precision rendezvous sensor called the video meter to bring it in to dock.

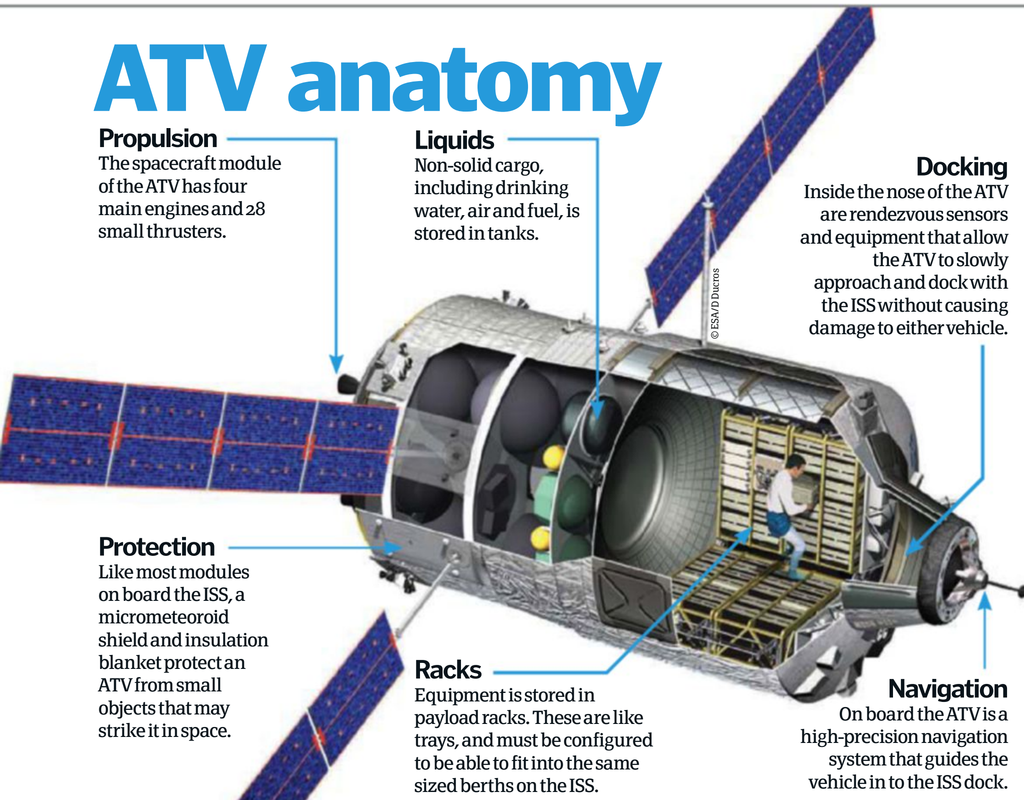
THE STATS
HOW AN ATV MEASURES UP

LENGTH 10.7m (35.1ft) DIAMETER **4.5m (14.8ft)** SPAN 22.3m (73.2ft)

VOLUME **48m³ (1,695ft³)** LAUNCH MASS 20,700kg (45,636lb)

DID YOU KNOW? *The ESA hopes to upgrade the ATV into a human-carrying vehicle by 2020*

ATV anatomy



Propulsion
The spacecraft module of the ATV has four main engines and 28 small thrusters.

Liquids
Non-solid cargo, including drinking water, air and fuel, is stored in tanks.

Docking
Inside the nose of the ATV are rendezvous sensors and equipment that allow the ATV to slowly approach and dock with the ISS without causing damage to either vehicle.

Protection
Like most modules on board the ISS, a micrometeoroid shield and insulation blanket protect an ATV from small objects that may strike it in space.

Racks
Equipment is stored in payload racks. These are like trays, and must be configured to be able to fit into the same sized berths on the ISS.

Navigation
On board the ATV is a high-precision navigation system that guides the vehicle in to the ISS dock.

Solar power
Four silicon-based solar arrays in an X shape provide the ATV with the power it needs to operate in space.

Currently, ESA ground control pilots the ATVs remotely

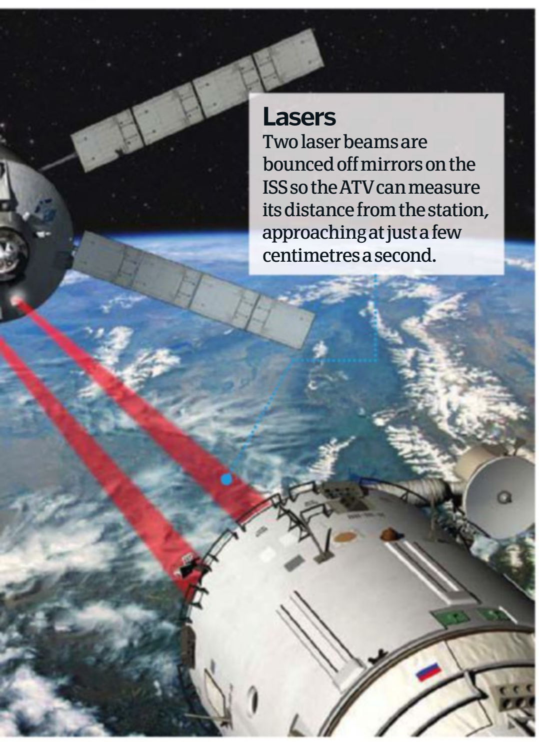
The MPLM was transported inside NASA's Space Shuttle

Other resupply vehicles

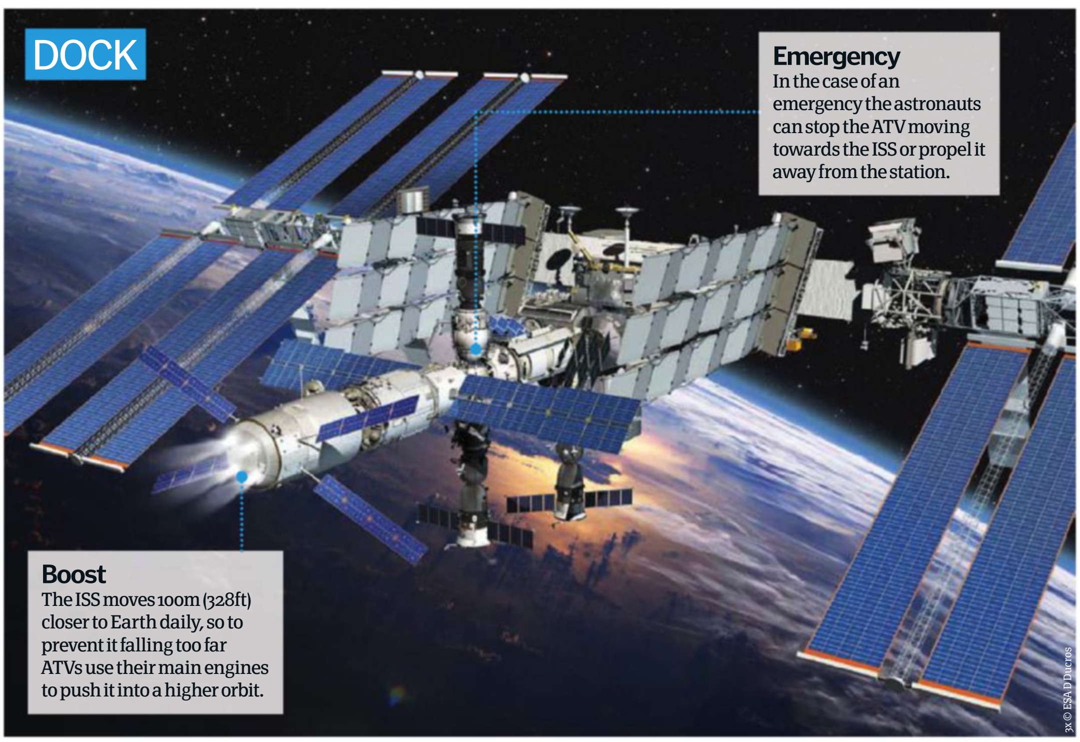
The ESA's automated transfer vehicle isn't the only spacecraft capable of taking supplies to the ISS. Since its launch, three other classes of spacecraft have been used to take cargo the 400 kilometres (250 miles) above Earth's surface to the station. The longest serving of these is Russia's Progress supply ship, which between 1978 and the present day has completed over 100 missions to Russia's Salyut 6, Salyut 7 and Mir space stations, as well as the ISS.

Succeeding Progress was the Italian-built multipurpose logistics module (MPLM), which was actually flown inside NASA's Space Shuttle and removed once the shuttle was docked to the space station. MPLMs were flown 12 times to the ISS, but one notable difference with the ATV is that they were brought back to Earth inside the Space Shuttle on every mission. The ATV and MPLM share some similarities, though, such as the pressurised cargo section, which is near identical on both vehicles.

The last and most recent resupply vehicle is the Japanese H-II transfer vehicle (HTV). It has completed one docking mission with the ISS to date, in late 2009, during which it spent 30 days attached to the station.



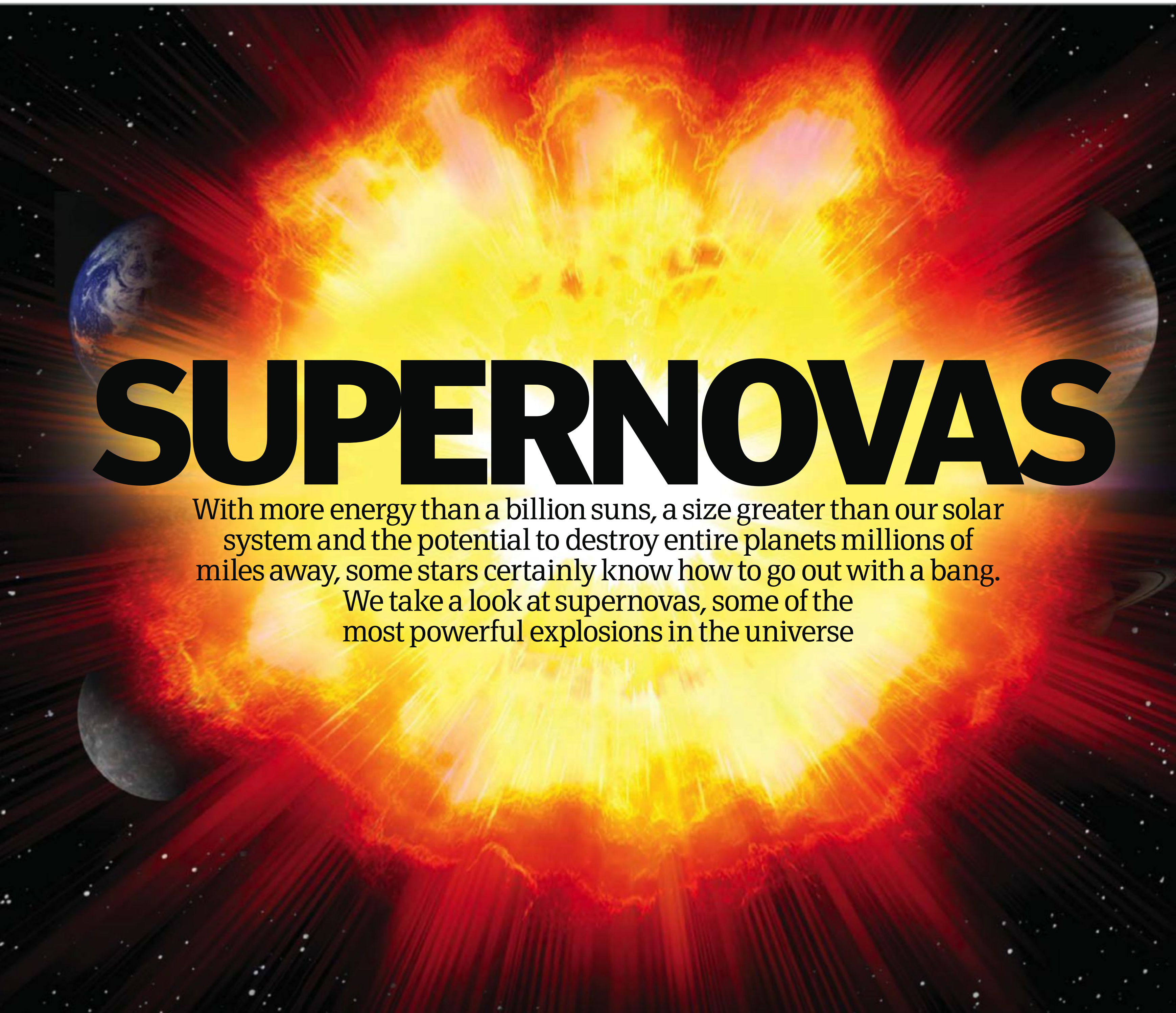
Lasers
Two laser beams are bounced off mirrors on the ISS so the ATV can measure its distance from the station, approaching at just a few centimetres a second.



DOCK

Emergency
In the case of an emergency the astronauts can stop the ATV moving towards the ISS or propel it away from the station.

Boost
The ISS moves 100m (328ft) closer to Earth daily, so to prevent it falling too far ATVs use their main engines to push it into a higher orbit.



SUPERNOVAS

With more energy than a billion suns, a size greater than our solar system and the potential to destroy entire planets millions of miles away, some stars certainly know how to go out with a bang. We take a look at supernovas, some of the most powerful explosions in the universe

When we delve into certain realms of astronomy, the scale of events and objects are often impossibly large to imagine. If we think of planets like Earth and Mars we can at least get some sort of grasp as to their size, as we can consider them relative to other bodies. As we get to bigger objects, like Jupiter and the Sun, our understanding gets somewhat muddled, but we can still comprehend how enormous they are by using Earth as a starting point (for example, the Sun is over 100 times the size of Earth). It's when we get to the larger celestial occurrences, like supergiant stars and black holes, however, that things really start to become unfathomable. In this article we'll be taking a look at one of these mammoth celestial events – supernovas – and we'll try to get our heads around just how large, powerful and crucial they are.

Supernovas have fascinated astronomers for millennia, appearing out of nowhere in the night sky and outshining other stars with consummate ease. The first recorded supernova, known today as SN 185, was spotted by Chinese astronomers in 185 AD and was apparently visible for almost a year. While this is the first recorded sighting, there have doubtless been many supernovas in preceding years that confounded Earth dwellers who were unable to explain the sudden appearance of a bright new star in the sky.

One of the most notable supernova events likely occurred about 340,000 years ago when a star known as Geminga went supernova. Although it was unrecorded, astronomers have been able to discern the manner of its demise from the remnant neutron star it left behind. Geminga is the closest known supernova to have exploded near Earth, as little as 290 light years away. Its proximity to Earth meant that it might have lit up the night sky for many months, casting its own shadows and

Head to Head
SUPERNOVA RECORDS

CLOSEST

1. Betelgeuse
Expected to explode within a million years, this star, which is 18 times the mass of the Sun, is just 640 light years from Earth.

SOONEST

2. Eta Carinae
This giant star – which is 100 times the mass of our Sun and over 8,000 light years away – could go supernova in just 10,000 years time.

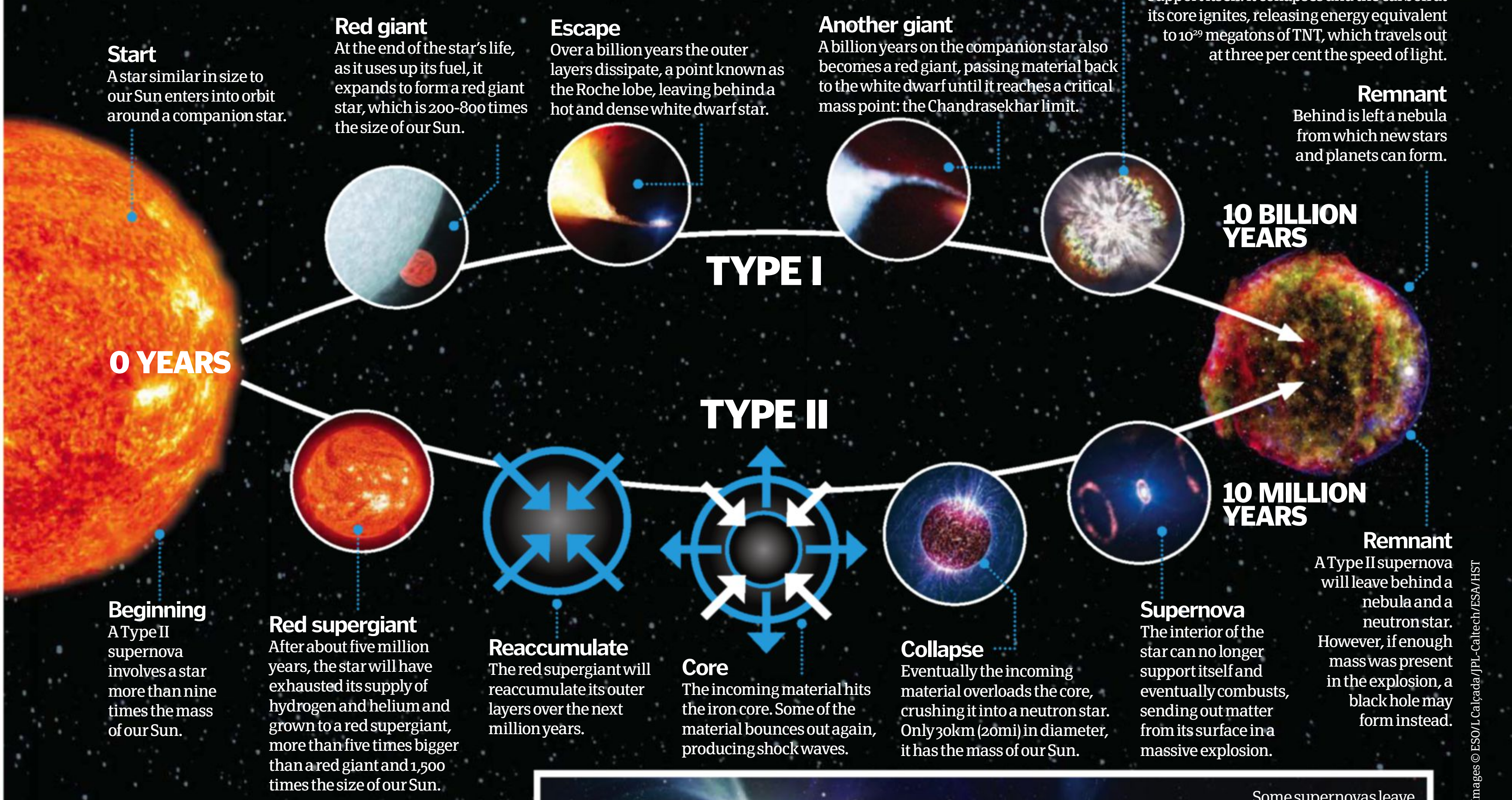
BIGGEST

3. SN 2006gy
In 2006 this giant supernova from a star 150 times the mass of our Sun was discovered 238 million light years away.

DID YOU KNOW? *Supernova is derived from the Latin term nova, meaning new, to denote the next phase in a star's life*

Countdown to a supernova

What events lead up to the explosion of the two known types of supernova?



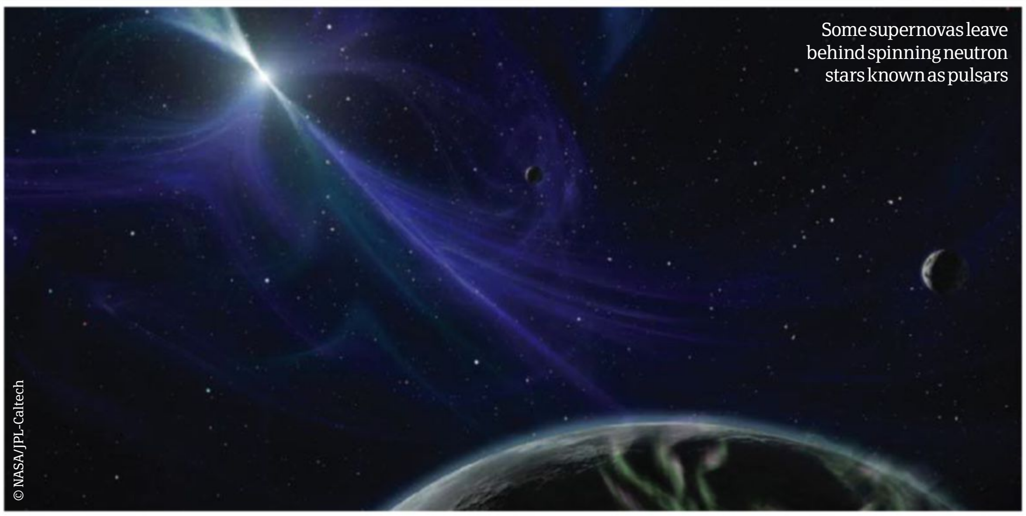
Images © ESO/L Calçada/JPL-Caltech/ESA/HST

"Geminga is the closest known supernova to have exploded near Earth, as little as 290 light years away"

rivalling the moon for brightness, turning night into day. So bright and large was this supernova that the ancients would have seen the light of it stretching from horizon to horizon. Left behind after this supernova was a neutron star rapidly rotating at about four times a second, the nearest neutron star to Earth and the third largest source of gamma rays to us in our observations of the cosmos. Other notable stellar explosions include Supernova 1987A, a star located in the Large Magellanic Cloud that went supernova in 1987. This originated from a supergiant star known as Sanduleak -69°202. It almost outshone the North Star (Polaris) as a result of its brightness, which was comparable to 250 million times that of the Sun.

It is a testament to the scale of these explosions that even ancient civilisations with limited to no astronomical equipment were able to observe them. Supernovas are bright not only visually but in all forms of electromagnetic radiation. They throw out x-rays, cosmic rays, radio waves and, on occasion, may be responsible for causing giant gamma-ray bursts, the largest known explosions in the universe. It is by measuring these forms of electromagnetic radiation that astronomers are able to glean such a clear picture of the formation and demise of supernovas. In fact, it is estimated that 99 per cent of the energy that a supernova exerts is in various forms of electromagnetic radiation other than visible light, making the study of this invisible (to the naked eye at least) radiation incredibly important, and something to which many observatories worldwide are tuned. Another type of stellar explosion you may have heard of is a nova. This is similar in its formation to a supernova, but there is one key difference post explosion: a supernova obliterates the original star, whereas a nova leaves behind an intact star somewhat similar to the original progenitor of the explosion.

Our understanding of the universe so far suggests that pretty much everything runs in cycles. For



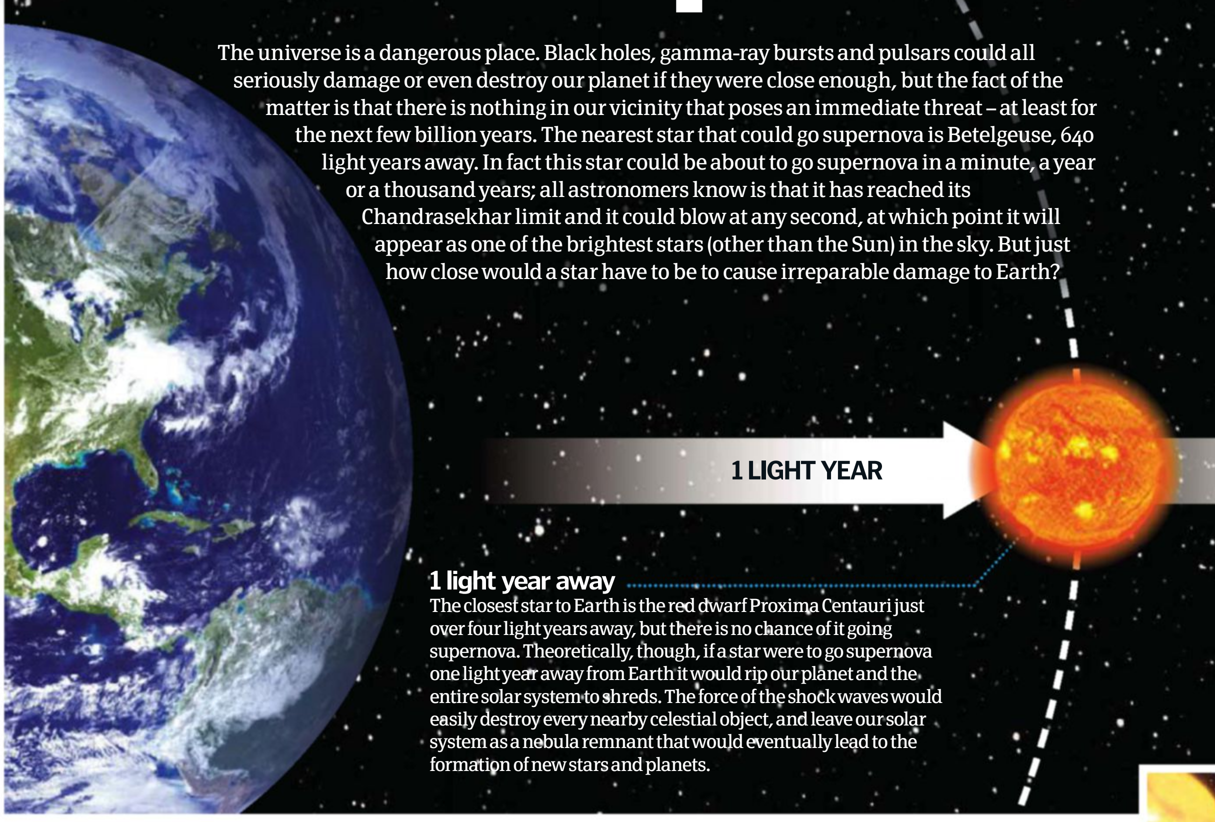
Some supernovas leave behind spinning neutron stars known as pulsars

© NASA/JPL-Caltech

Only a Type II supernova can become a black hole

© NASA/JPL-Caltech

Could a supernova



The universe is a dangerous place. Black holes, gamma-ray bursts and pulsars could all seriously damage or even destroy our planet if they were close enough, but the fact of the matter is that there is nothing in our vicinity that poses an immediate threat – at least for the next few billion years. The nearest star that could go supernova is Betelgeuse, 640 light years away. In fact this star could be about to go supernova in a minute, a year or a thousand years; all astronomers know is that it has reached its Chandrasekhar limit and it could blow at any second, at which point it will appear as one of the brightest stars (other than the Sun) in the sky. But just how close would a star have to be to cause irreparable damage to Earth?

1 light year away
The closest star to Earth is the red dwarf Proxima Centauri just over four light years away, but there is no chance of it going supernova. Theoretically, though, if a star were to go supernova one light year away from Earth it would rip our planet and the entire solar system to shreds. The force of the shock waves would easily destroy every nearby celestial object, and leave our solar system as a nebula remnant that would eventually lead to the formation of new stars and planets.

example, a star is born from a cloud of dust and gas, it undergoes nuclear fusion for billions of years, and then destroys itself in a fantastic explosion, creating the very same dust and gas that will lead to the formation of another star. It is thanks to this cyclic nature of the universe that we are able to observe events that would otherwise be extremely rare or nonexistent. If stars were not constantly reforming, there would be none left from the birth of the universe 13.7 billion years ago.

As destructive as they may be, supernovas are integral to the structure and formation of the universe. It is thought that the solar system itself formed from a giant nebula left behind from a supernova while, as mentioned earlier, supernovas are very important in the life cycle of stars and lead to the creation of new stars as the old ones die out. This is because a star contains many of the elements necessary for planetary and stellar formation including large amounts of helium, hydrogen, oxygen and iron, all key components in the structure of celestial bodies. On top of these, many other elements are thought to form during the actual explosion itself.

There's no doubt that supernovas are one of the most destructive forces of the universe, but at the same time they're one of the most essential to the life cycle of solar systems. As we develop more powerful telescopes over the coming years we will be able to observe and study supernovas in more detail, and possibly discover some that do not fall into our current classification of Type I or Type II. The study of supernovas alone can unlock countless secrets of the universe, and as we further our understanding of these colossal stellar explosions we'll be able to learn more about the cosmos as a whole.

This image of the Crab Nebula shows the visible (red) and x-ray (blue) radiation left after a supernova

© NASA/CXC/HST/ASU

All that remains…

What is left behind once a star goes supernova?

Inside a massive star, before it goes supernova, the nuclei of light elements like hydrogen and helium combine to form the basic constituents of other celestial bodies and even life (such as carbon and oxygen). Stars release these vital elements when they go supernova, providing the material for new stellar and planetary formation.

To date there are roughly 300 known supernova remnants in the universe. Depending on the type and mass of a supernova (see the diagram on the previous page), the remnants left behind can be one of several things. In the vast majority of cases some form of nebula will be left behind. Inside this nebula will often be a spinning neutron star. The rate of spin of this neutron star, also known as a pulsar, depends on the original mass of the exploded star, with some pulsars rotating upwards of a thousand times per minute!

These highly dense stars contain the mass of the Sun packed into an area no bigger than the city of London. If the supernova remnant exceeds four solar masses (the mass of our Sun), due to an extremely heavy initial star or by more material accumulating around the remnant from nearby objects, then the remnant will collapse to form a black hole instead of continuing to expand.

© NASA/JPL-Caltech

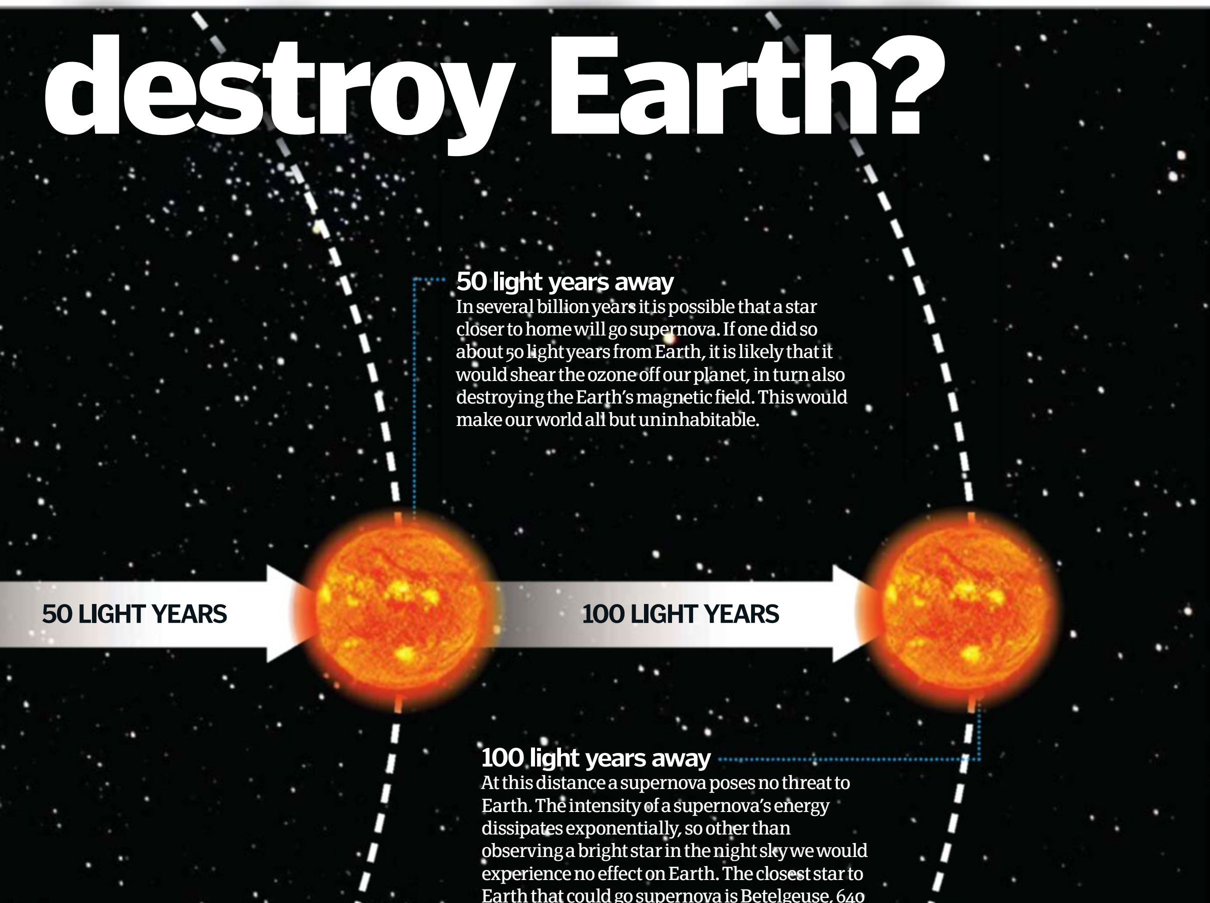
© XMM-Newton/Chandra/WISE/Spitzer

DID YOU KNOW?

Superstar
One of the most famous supernova remnants in reasonably close proximity to Earth is the Crab Nebula, the remains of a star that went supernova in 1054, about 6,000 light years away. A spinning neutron star known as the Crab Pulsar is located at its centre.

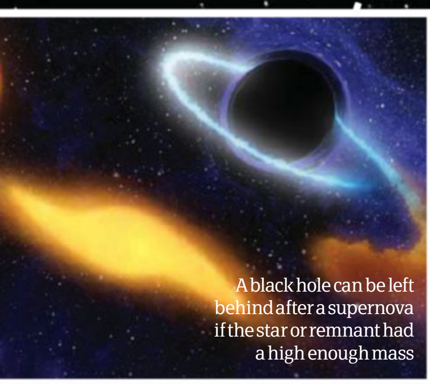
DID YOU KNOW? The Chandrasekhar limit is named after Indian astrophysicist Subrahmanyan Chandrasekhar

destroy Earth?



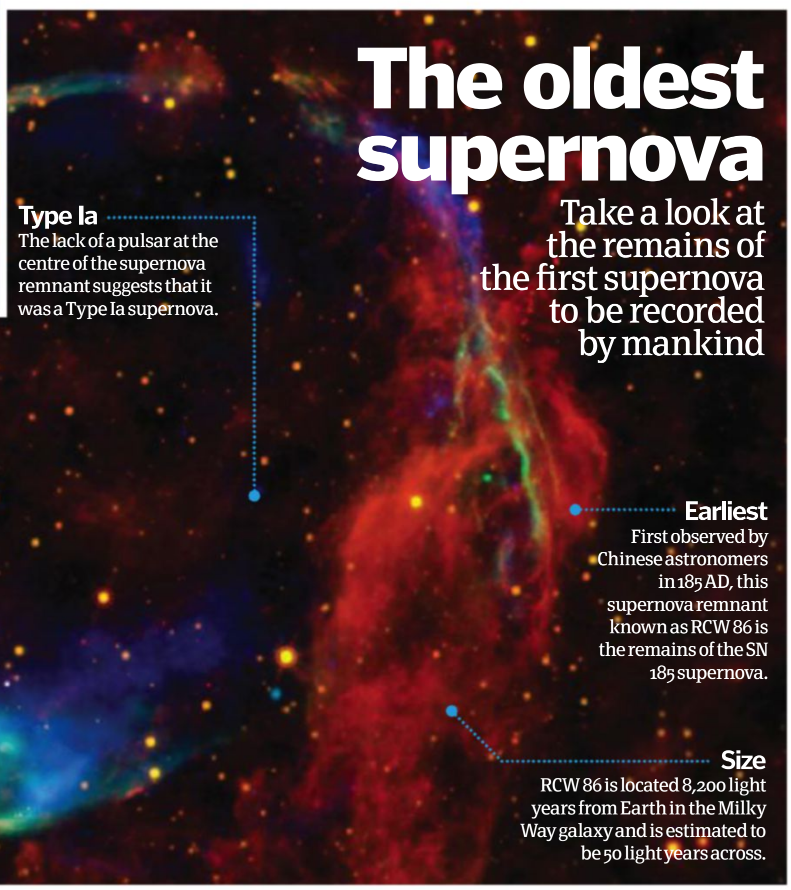
50 light years away
In several billion years it is possible that a star closer to home will go supernova. If one did so about 50 light years from Earth, it is likely that it would shear the ozone off our planet, in turn also destroying the Earth's magnetic field. This would make our world all but uninhabitable.

100 light years away
At this distance a supernova poses no threat to Earth. The intensity of a supernova's energy dissipates exponentially, so other than observing a bright star in the night sky we would experience no effect on Earth. The closest star to Earth that could go supernova is Betelgeuse, 640 light years away, so it poses no threat to us.


A black hole can be left behind after a supernova if the star or remnant had a high enough mass

The oldest supernova

Take a look at the remains of the first supernova to be recorded by mankind



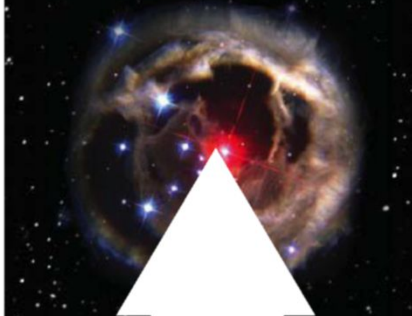
Type Ia
The lack of a pulsar at the centre of the supernova remnant suggests that it was a Type Ia supernova.

Earliest
First observed by Chinese astronomers in 185 AD, this supernova remnant known as RCW 86 is the remains of the SN 185 supernova.

Size
RCW 86 is located 8,200 light years from Earth in the Milky Way galaxy and is estimated to be 50 light years across.

SIZE OF A SUPERNOVA

How much energy does a supernova release?



1,000,000,000,000,000,000,000 yottajoules (10^{44} joules)
Energy released from a supernova

1,000 zettajoules (1 yottajoule)
Total energy from the Sun that reaches Earth in a year

1,000 exajoules (1 zettajoule)
Energy of the entire Earth's petrol reserves

1,000 petajoules (1 exajoule)
Estimated energy in the 2011 Japanese earthquake and tsunami

1,000 terajoules (1 petajoule)
Energy in 1 megaton of TNT

1,000 gigajoules (1 terajoule)
Approximate energy in a small nuclear bomb

1,000 megajoules (1 gigajoule)
Average energy in a lightning bolt

1,000 kilojoules (1 megajoule)
Approximate daily male energy intake

1,000 joules (1 kilojoule)
Explosion of less than 1g (0.03oz) of TNT

1 joule of energy
Flash of a camera

TRANSPORT

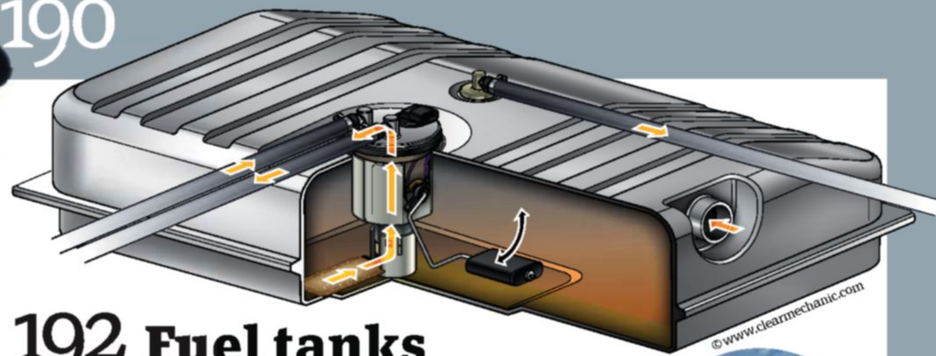
190

Fighter planes

205

219

Super tankers



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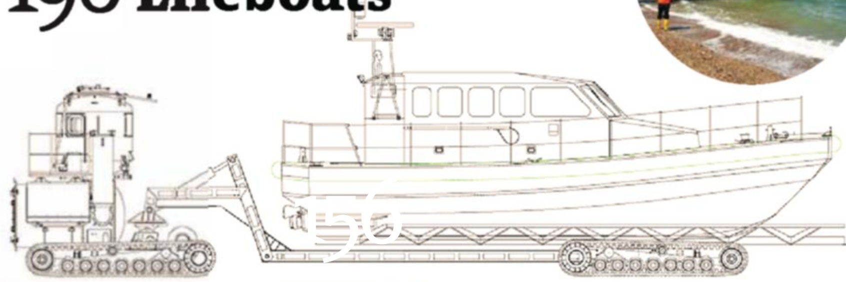

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HOW DO PLANES FLY?

Pilot © Science Photo Library

Take to the skies and discover how hundreds of tons of metal can remain airborne in this feature explaining the fundamental principles of lift and flight

Takeoff and landing
What forces are in action?

Stage 1

Acceleration
To generate adequate lift from the ground, the pilot increases the size and camber (top curvature) of the wings by extending flaps at the back, and slats in the front.

Stage 2

Take-off
The pilot raises the tail elevators, and rushing air pushes the tail down. This raises the nose up, and increases the wings' angle of attack, producing enough lift for takeoff.

Testing to the limit
1 German aviator Otto Lilienthal tested more than a dozen glider designs by jumping from cliffs and rooftops. He died in 1896 after a strong gust caused his plane to crash.

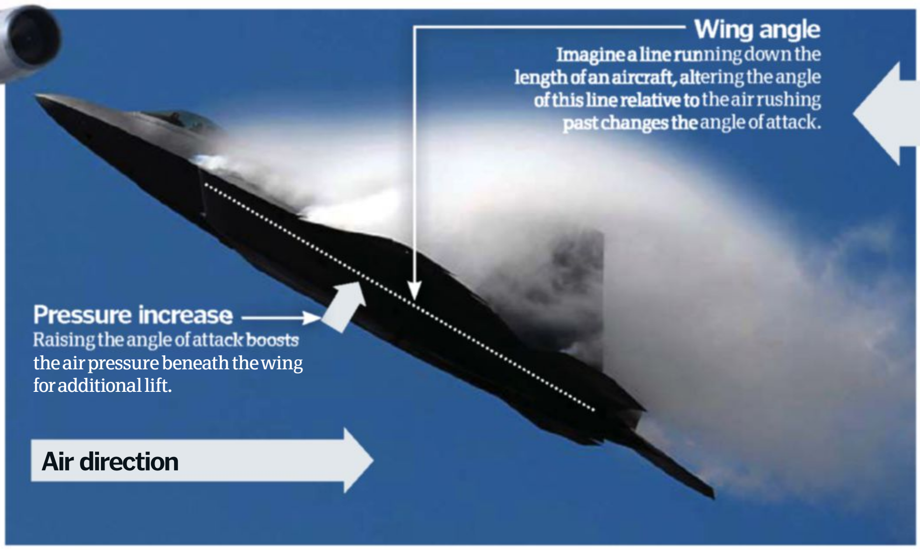
Tech speeds up
2 In the National Air Races of the Thirties, enthusiasts cooked up innovations, including retractable landing gear, powerful engines, wing flaps, and streamlined cockpits.

Sea planes once ruled
3 Before airports, passengers often travelled by seaplane. Models like the two-floor Boeing 314 Flying Clipper were essentially flying hotels, with bedrooms and a dining room.

Chuck Yeager
4 On 14 October 1947, Yeager had two cracked ribs after falling off a horse the previous day. But he still strapped into the rocket-powered Bell X-1 and broke the sound barrier.

A glider went to space
5 SpaceShipOne completed the first private manned spaceflight. Made mainly of epoxy plastic and carbon fibre, it got to space on rocket power but glided home.

DID YOU KNOW? Since propeller tips spin faster than the hub, you need a twist to keep an even thrust



Adjusting the angle of attack

Discover for yourself how the pilot makes the plane climb

Imagine a straight line going through the middle of a wing. The angle of attack is the angle of this line relative to the direction of rushing air. As you increase this angle, you boost the air pressure under the wing, resulting in greater lift. Pilots increase the angle of attack in order to climb, and decrease it to level out or dive.

Channel your inner seven-year-old, and try it yourself. Carefully, stick your hand out the window of a moving car with your palm down, and your thumb side tilted slightly up. Tilt the thumb side up, and your hand directs even more air downward, and you feel a greater upward push. If you keep pivoting your hand, however, you'll reach a point where air can't flow easily around it. The lift drops suddenly, and your hand flies straight back. In airplanes, this is called the stall point, and it's usually bad news for pilots.

When we finally made the pivotal breakthrough, man-made flight took off in a hurry. In 45 years, we went from the Wright Brothers' beach hops to businessmen harassing stewardesses at 20,000 feet and test pilots moving faster than sound. Each leap forward came from ever-greater feats of engineering.

For millennia, would-be aviators knew bird flight had something to do with wing structure, but were clueless regarding the details. As it turns out, the shape of a wing is optimised to generate lift, an upward force caused by manipulating airflow. A wing has a rounded leading edge with a slight upward tilt, a curved topside, and a tapered trailing edge pointing downward. This shape alters the flow of air molecules into a downward trajectory. This results in – as Newton put it in his Third Law of Motion – "an equal and opposite reaction." When the wing pushes the air molecules down, the molecules push the wing up with equal force. The airflow also creates a lower pressure area above the wing, which essentially sucks the wing up.

Constructing wings is the easy part. To fly, you need to generate enough forward force – or thrust – to produce the necessary lift to counteract gravity. The Wright Brothers finally accomplished this by linking a piston engine to twin propellers. A plane propeller is simply a group of rotating wings shifted 90 degrees, so the direction of lift is forwards rather than upwards. In 1944, engineers upgraded to jet engines, which produce much greater thrust by igniting a mixture of air and fuel, and expelling hot gases backward.

A pilot controls a plane by adjusting movable surfaces on the main wings, as well as smaller surfaces and a wing-like rudder on the tail. By changing the shape and position of these structures, the pilot varies the lift force, acting on the different ends of the plane to essentially pivot the plane along three axes: its pitch (up or down tilt of the nose), roll (side to side rotation), and yaw (turn to the left or right).

For the sake of efficiency, engineers keep planes as light and aerodynamic as possible. The first planes – sparse wooden frames covered in fabric – were lightweight and open, which minimised drag, the backwards force of air resistance. But the structure was only strong enough to handle low speeds. 'Hot-rod' a Wright Brothers' plane with a jet engine, and the extra thrust would tear it apart. Along with more powerful engines, engineers had to develop stronger metal frameworks and streamlined aluminium alloy surfaces.

Modern fighter jets are manufactured from super-strong, lightweight composite material, applied in layers to form precise, aerodynamic shapes. This helps them get up to more than twice the speed of sound.

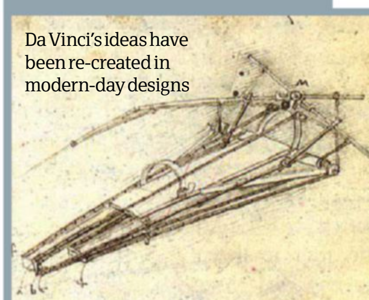
The da Vinci glider

In his 1505 treatise *Codex On The Flight Of Birds*, da Vinci uncovered fundamental flight principles and designed theoretical aircraft based on birds and bats. While his man-powered ornithopter (aircraft powered by flapping) and proto-helicopter were impractical, his glider seems feasible.

In 2002, glider expert Simon Sanderson built da Vinci's design for a BBC documentary. Scale model wind-tunnel testing showed the air stream moving around the glider to create a high-pressure area underneath, and a low pressure area above, which indicated that it could fly.

Sanderson's initial full-scale glider tended to pitch downwards, making it too unstable to fly safely. But after Sanderson added a tail, mentioned elsewhere in da Vinci's notes, paragliding champion Robbie Whittall successfully flew the glider, which tilts up with a pronounced angle of attack.

Unfortunately, da Vinci's notes weren't widely read until the 19th Century. It was another 490 years after his treatise before someone reinvented a working glider.

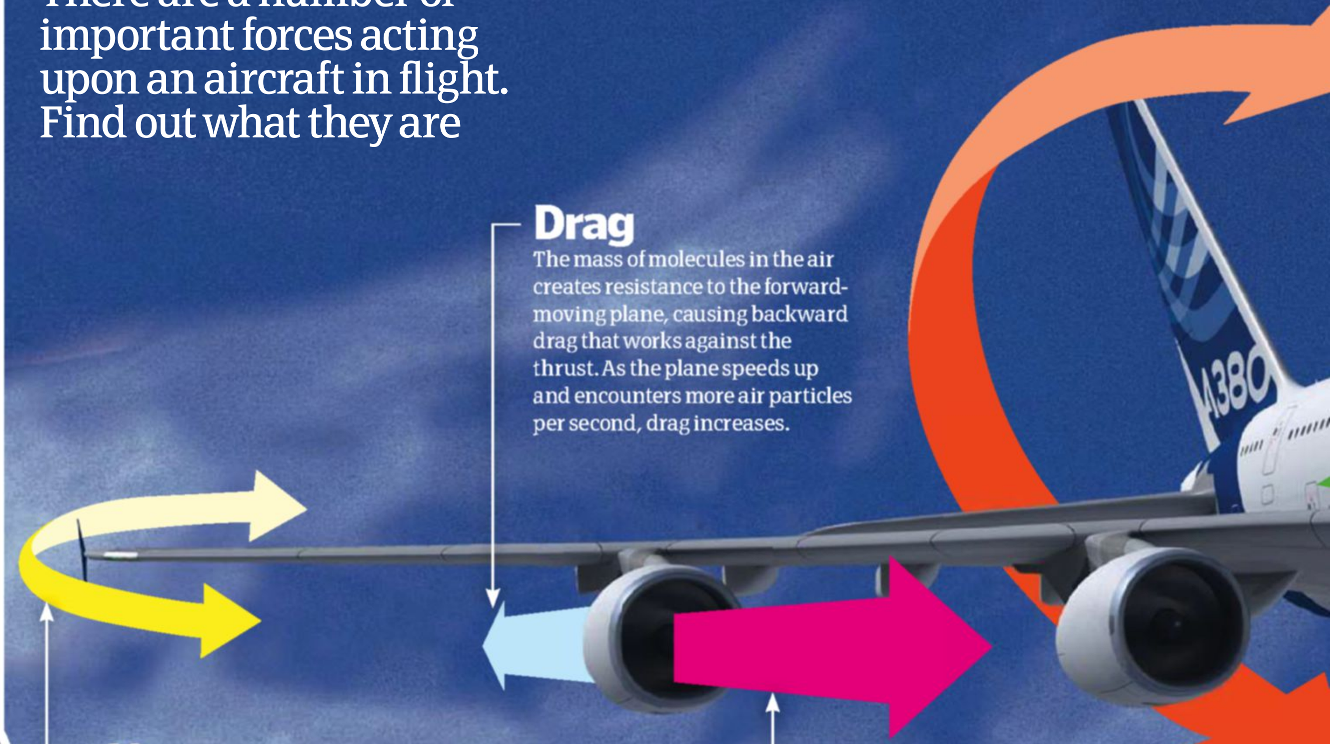

Da Vinci's ideas have been re-created in modern-day designs

Flight
In flight, the pilot retracts the flaps and slats, and continually adjusts the ailerons, rudder and elevators to manoeuvre the plane.

Landing
The pilot reduces thrust to slow the plane and extends the landing gear, flaps and slats. When it touches down, the pilot extends spoilers on top of the wing to quickly decrease the lift.

KNOW YOUR FLIGHT FORCES

There are a number of important forces acting upon an aircraft in flight. Find out what they are



Drag
The mass of molecules in the air creates resistance to the forward-moving plane, causing backward drag that works against the thrust. As the plane speeds up and encounters more air particles per second, drag increases.

Yaw
Planes have a vertical tail rudder, which is similar to the rudder on a boat. When you tilt the rudder to the left, rushing air will pivot the tail to the right. To turn successfully, it's necessary to adjust the yaw and roll simultaneously.

Thrust
The forward thrust of the plane, generated by propellers, jet engines or rockets, counteracts drag and moves the wings through the air to generate lift.

Roll
To roll the plane, the hinged wing surfaces, called ailerons, have to be adjusted. To roll right, the aileron on the right wing has to be raised, which reduces lift, while simultaneously lowering the aileron on the left wing, which increases lift. The left wing rises and the right wing drops, rolling the plane to the right.

Biplanes
A larger wing surface area usually means that more lift can be generated. However, massive wings could impact negatively on steering. One way to increase the wing surface area without making giant wings is to introduce a second set of wings.

Flight at different heights

F-35
The F-35 has a small wingspan of 10.6 metres (35 feet), but with its Mach 1.6+ top speed, it generates enough lift to fly at a height of 18,300 metres (60,000 feet).

Boeing 747
Thanks in part to its 68-metre (228-foot) wingspan, the Boeing 747-8 can safely reach a height of 18,300 metres (43,000 feet). However, because there is minimal air at that altitude, aggressive climbing can lead to catastrophic stalling.

Antonov
The Antonov AN-225 has an 88-metre (290-foot) wingspan, but its weight hinders its lift, limiting it to a height of 11,000 metres (36,100 feet).

Albatros D-II
Because air density drops with altitude, the wings generate less lift, and eventually can't function properly. With a 177-km/h (110mph) top speed, the 1914 Albatros D-II had a service ceiling of 5,150 metres (16,990 feet).

Wright Flyer
The 1903 Wright Flyer's 12-horsepower engine only generated enough thrust to get three metres (ten feet) above the ground. Boosting the speed to go higher would have likely broken the relatively fragile plane.

Head to Head MASSIVE AIRCRAFT

GREATEST WINGSPAN

1. Hughes H-4 Hercules
Also known as the Spruce Goose, Howard Hughes' wooden, eight-engine plane sports a 97.5m wingspan. It flew only once, in 1947.

TALLEST

2. The Airbus A380
An 24m tail lands the A380 a spot in the record books. The double-decker commercial jet seats 852 people.

HEAVIEST AND LONGEST

3. Antonov An-225 Mriya
Before the Soviet Union dissolved, it commissioned this 590-ton, 84m-long cargo aircraft to transport its Buran Space Shuttle.

DID YOU KNOW? *Many fighter jets are aerodynamically unstable. Flying requires the computer to make constant adjustments*

Lift
The relative pressure of air rushing over and under the wings generates the upward lift force that keeps the plane aloft. In a typical small plane, the force of lift equals about ten times the force of thrust. Lift increases with the wings' surface area.

Pitch
Tail wings called stabilisers include adjustable flaps called elevators. When the elevators are tilted up, they generate lift that forces the tail downward. The nose tilts up, increasing the wing's angle of attack, causing the plane to climb. Tilting the elevators down lifts the tail, pitching the plane forward into a dive.

Gravity
Planes need sufficient lift to overcome the continual downward force of gravity. The heavier the plane, the more lift is needed – either from larger wings, greater thrust, or both.

© Airbus

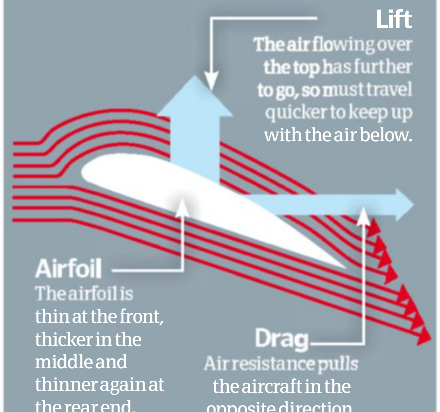
The forces on an airfoil

Discover the science of aircraft wings

More than a century after the Wright Brothers, physicists are still debating exactly how wings work. Accessible explanations for the rest of us can't help but leave things out, and some common answers are flat-out wrong.

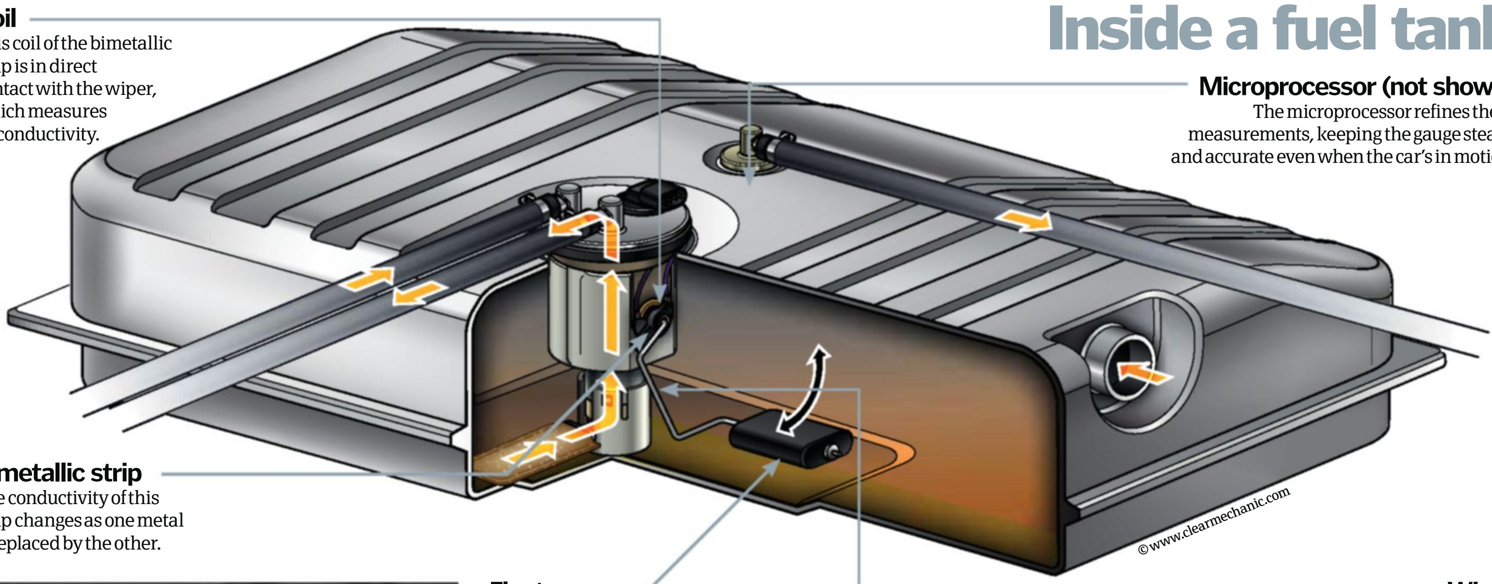
The crucial thing to understand is that air is a fluid, and that wings alter the flow of that fluid. The top and bottom of the wing both deflect air molecules downwards, which results in an opposite upward force. In the typical airfoil design, the top of the wing is curved. Flowing air follows this curve, causing it to leave the wing at a significant downward angle. This also generates a low-pressure area above the wing, which helps pull it up.

Long, skinny wings are more efficient because they produce minimal drag proportional to lift. But they're also fragile and slow to manoeuvre. In contrast, stubby wings offer high agility and strength, but require more thrust to produce lift.



Longer wings produce mimimal drag

Inside a fuel tank



How your fuel gauge works

No one wants to be running on empty, making this fuel monitor a vital part of every automobile

Fuel gauges operate on electrical resistance, using a float with an attached metallic rod as the internal 'needle'. A wiper conducts electrical current from the rod to the gauge and the more of the rod that's exposed, the less conductive it becomes, which in turn reduces the fuel gauge level. This older system is effective but works on a relative scale; you're never sure just how close to empty the tank is.

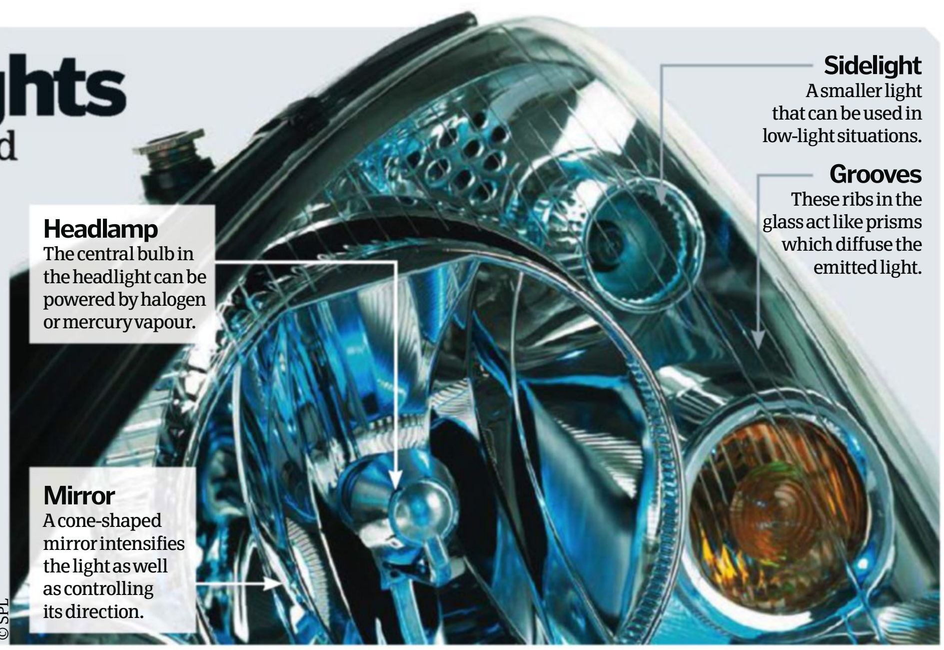
Modern fuel gauges work off the same principle but add a microprocessor to read the resistance in the tank. They can also compensate for the shape of the tank, calculating the volume of fuel remaining far more accurately. Even better, the microprocessor can 'dampen' needle movement, meaning that your fuel gauge doesn't swing wildly as you turn corners or climb hills, which sloshes the fuel in the tank, along with the float, exposing more of the rod.

Modern headlights

How cars illuminate the road ahead

In many ways, the key to a headlight lies not in the light itself, but in what lies in front and behind it. The parabolic mirror positioned behind the headlight's bulb is designed to concentrate and redirect the light back out the front of the device. At the front of the headlight, meanwhile, the glass in the casing is reticulated to act as a prism, diffusing the light and projecting it across a much wider area. This is further aided in modern cars by high-intensity discharge (HID) bulbs. These use mercury vapour instead of the traditional halogen bulbs to burn both brighter and faster.

The driver can also 'dip' their headlights to prevent obscuring oncoming drivers' vision, or to avoid the glare from fog. This is done by slightly altering the angle of the mirror behind the headlamp, projecting the same intensity of illumination but at a lower angle directed at the road.



© SPL

Catamarans can be sail or motor powered

© Lloyd Images

Catamarans

We take a look inside these dual-hulled boats

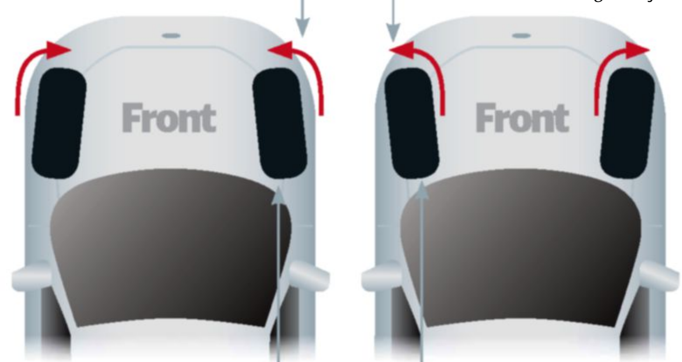
Catamarans have a number of design elements that put them among the fastest sail and motorised vehicles on the seas. The hulls of a sail-powered catamaran are often made of fibreglass fabric, foam or another lightweight material, allowing them to catch a large amount of wind, and their wide berth and light frame means that they can rise up onto just one of their hulls when travelling at speed. This allows the catamaran to reach a higher speed, as there is less contact with the water.

When compared to a single-hulled boat, the twin-hull shape of a catamaran has a number of advantages. For starters, the wide berth of the two hulls makes the whole boat very stable. This means that the sail is more likely to stay upright in a heavy gust than that of a monohull, allowing it to draw more power and be larger than that on a single-hull. This stability also means that a catamaran does not need a counterweight to prevent it tipping over, making it very light and easily manoeuvrable, although there is an increased risk of capsizing. Finally, the hulls of a catamaran are much thinner than those on a single-hulled boat, meaning that there is a smaller surface area in contact with the water and therefore far less friction, consequently allowing them to reach higher speeds.

Car tracking

How does a car alter its straight-line stability?

The toe (or tracking) of a car is a measure of the angle of the wheels relative to the forward direction, with an inwards (toe-in) and outwards (toe-out) direction increasing and decreasing straight-line stability, respectively. The latter requires more steering to keep the car in a straight line, but makes cornering easier. The front wheels of road cars are generally calibrated to have greater toe-in, while racing cars often use a toe-out setup for increased cornering speed.



1. Toe-in
When the wheels point slightly inwards, they will give the car greater straight-line stability.

2. Toe-out
Pointing the wheels slightly outwards will reduce straight-line stability but increase cornering ability.

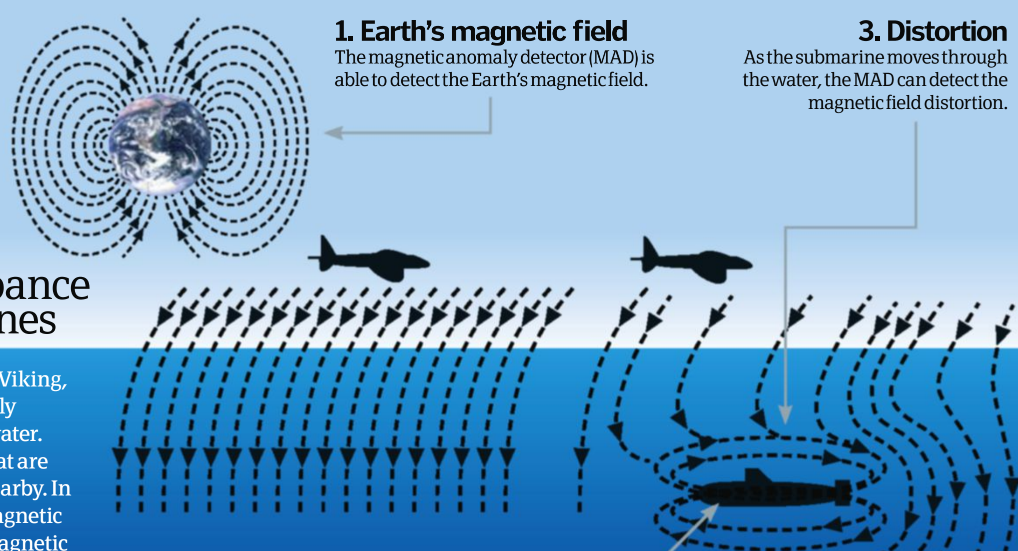
3. Understeer
Using toe-in, a car will be more likely to turn slowly into a corner and understeer, as the wheels cannot turn as far as with a toe-out configuration.

4. Oversteer
Toe-out will often result in the car turning more than is needed into a corner, and the back of the car may swing out and skid.

Magnetic submarine detectors

How planes sense a disturbance in the force to find submarines

Some planes, such as the US Navy's now-retired S-3 Viking, are able to use something called a magnetic anomaly detector (MAD) boom to detect submarines underwater. Ferromagnetic materials, such as iron, are those that are attracted to magnets, disturbing magnetic fields nearby. In this case, a submarine (itself composed of a ferromagnetic material such as a steel alloy) distorts the Earth's magnetic field as it moves through the sea. A plane fitted with a MAD is able to detect this disturbance and ultimately pinpoint the position of the submarine underwater. The detector is placed at the end of a boom to eliminate interference from the plane itself.



1. Earth's magnetic field
The magnetic anomaly detector (MAD) is able to detect the Earth's magnetic field.

3. Distortion
As the submarine moves through the water, the MAD can detect the magnetic field distortion.

2. Submarine
The submarine, made of a ferromagnetic material such as steel, distorts the Earth's magnetic field.

4. Detection
Once the distortion has been located, the position of the submarine can be pinpointed to varying degrees of accuracy.

The CH-46 Sea Knight is designed to provide all-weather, 24-hour assault transport for US Marine Corps combat troops. As such, it is equipped with a wide variety of countermeasure devices

Decoy flares

One of the most widely used aerial countermeasures in the world, decoy flares offer a simple but robust last line of defence against incoming missiles

Decoy flares, as commonly used by military aircraft, work by generating a heat signature in excess of the launch vehicle's jet engines. This has the effect of confusing any incoming heat-seeking missile's homing system into locking on to the flares' signatures instead of the aircraft's, causing it to explode at a safe distance and saving the pilot's life.

There are two main types of countermeasure flare – pyrophoric and pyrotechnic. The former is activated automatically on contact with air and the latter by the mechanical removal of a friction cap prior to firing. Pyrotechnic flares use slow-burning fuel-oxydiser mixtures to generate heat, such as MTV (magnesium/Teflon/Viton), while pyrophoric variants use either ultra-fine, aluminium-coated iron platelets or liquid compounds such as triethylaluminium. The composition of either type of flare is often tailored to counter specific missile systems or to mimic the launch jet's heat signature.

All military aircraft being built today are fitted with automatic flare dispensing systems, which actively track incoming missiles and launch flares accordingly at optimal range to avert damage, while older or civilian aircraft usually require the pilot to activate the flare launches manually. Systems are fairly flexible and flares can be dispensed one at a time, over long or short intervals and even, if desired, in large clusters – as demonstrated by the CH-46E Sea Knight in this stunning image.

What is it?

This image shows a Boeing CH-46 Sea Knight helicopter dumping a cluster of decoy flares into the atmosphere. Flares are a form of aerial infrared countermeasure employed to trick heat-seeking surface-to-air or air-to-air homing missiles.

How to launch a

How does the Supacat Launch & Recovery System work?

When a lifeboat crew gets an emergency call, or shout, they aim to be hitting the waves as fast as possible. The North Sea can render a capsized sailor or distressed swimmer unconscious through hypothermia in under five minutes, so every minute counts. If a lifeboat is land-based in high tidal areas, the crew have to get it off land and into the sea as soon as possible.

Lifeboats are highly specialist machines, fitted with such features as carbon fibre suspension seats, so crews can strap themselves in and avoid being thrown around in rough conditions; self-righting hulls to correct themselves in the event of capsizing; and, on the latest boats, Systems and Information Management Systems (SIMS). This enables the crew to control all the boat's functions from the safety of the bridge cockpit in extreme weather. But while lifeboats are hi tech, the equipment used to tow and launch them hasn't kept pace and has usually been modified from commercial vehicles such as quad bikes and farm tractors, and even, in some cases – such as the independent Southport Lifeboat – construction dumper trucks.

However, when the Royal National Lifeboat Institution (RNLI) takes delivery of the Supacat Lifeboat Launch & Recovery System (L&RS) in 2013, its volunteer crews will be getting a vehicle as cutting edge as the boats it launches.

In the event of a shout, the L&RS drives a lifeboat to the water with its entire crew on board. In the cab, the driver/operator's seat and controls can swivel through 180 degrees on a hydraulic turntable, so he can either use the L&RS to pull a lifeboat behind his position or push it in front. The steering controls (two joysticks) are automatically adjusted by an on-board computer, so whichever way the driver's facing he still steers in the same direction. Computers also govern the engine, giving the vehicle three set speed options so the operator can concentrate purely on the delivery and launch and not on controlling the 12.7-litre Scania diesel power unit.

Once at the water's edge, the operator lowers the L&RS, which can operate at a depth of up to 2.4 metres (that's nearly half a metre deeper than the deep end in an Olympic pool), and lifeboat into the water. For maximum control, the operator has the driving position set so he can see the boat in front of him. The coxswain (boat commander) guides the driver using hand signals from the boat deck. The lifeboat will always be launched bow first so it's facing in the right direction to go out to sea. The L&RS has a turntable built into its trailer so it can spin a lifeboat round, allowing for bow-first recoveries as well as launches.

Once into the water deep enough, the coxswain can activate a launch with a simple press of a button, which operates the mechanical locking system. This consists of hydraulically operated opposing wedges at the rear and a huge strop running over the bow, held in place by two hydraulic cylinders. Once released from the locking system, the boat simply floats off.

This is a massive improvement on the current launch system, which involves chains, pins and four men with wooden mallets. This old system required either extra ground crew, or four boat crew members to carry out the launch then climb aboard, adding valuable minutes to a shout.

After a shout, the crew beach the boat (run it aground), where the L&RS makes short work of getting it back on the trailer. It uses its massive winch, which is capable of hauling the equivalent of 16 Mini Coopers (27 tons), to pick up the boat. Recoveries can be quicker and easier, and it also means there's less chance of damage to the boat's water jets.

5 TOP FACTS LIFESAVING WATER CRAFT

CRV55

1 The world's largest cruise ship, the Oasis of the Seas, can boast the world's largest on-board life rafts. It carries 18 CRV55 catamarans, which can each hold 370 passengers.

The Original

2 The world's first shore-based lifeboat designed for sea rescues was built way back in 1790. Called the Original, she carried ten oarsmen and was in service for 40 years.

Shannon class

3 When the Shannon class lifeboat comes into service it will be the first RNLI offshore boat that uses water jets rather than propellers for propulsion.

SIMS

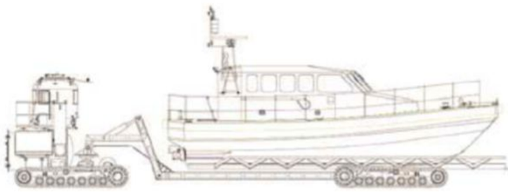
4 The Tamar was the first class of lifeboat to feature Systems and Information Management Systems (SIMS), which enables the crew to control all functions from the bridge.

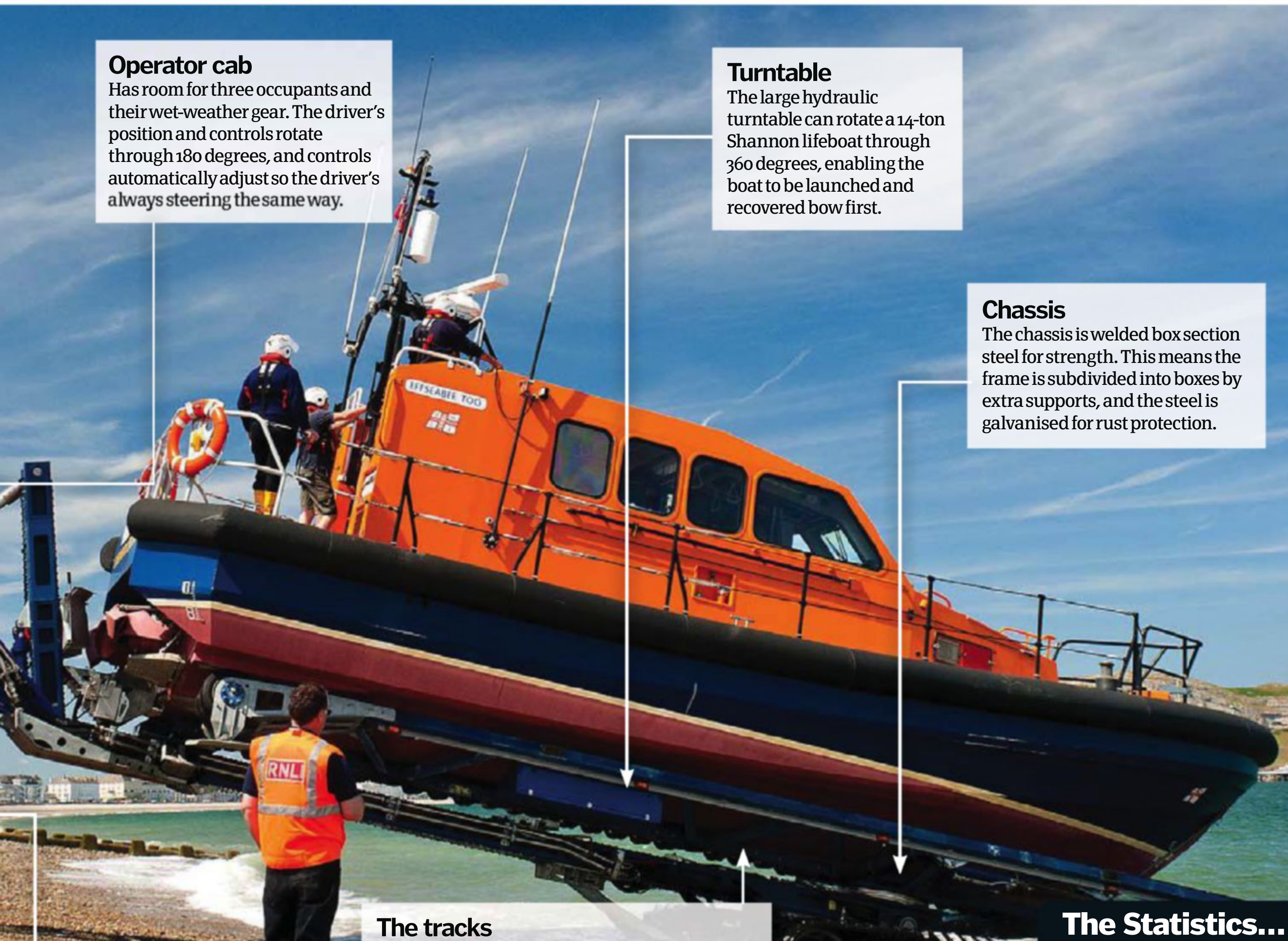
Nautilus Advanced Rescue Craft

5 British maritime company Nautilus has developed the Advanced Rescue Craft, which combines elements of both a jet ski and a rigid boat.

DID YOU KNOW? *In the event of getting stuck, the L&RS can be shut down and safely submerged to a depth of nine metres*

lifeboat





Operator cab
Has room for three occupants and their wet-weather gear. The driver's position and controls rotate through 180 degrees, and controls automatically adjust so the driver's always steering the same way.

Turntable
The large hydraulic turntable can rotate a 14-ton Shannon lifeboat through 360 degrees, enabling the boat to be launched and recovered bow first.

Chassis
The chassis is welded box section steel for strength. This means the frame is subdivided into boxes by extra supports, and the steel is galvanised for rust protection.

The tracks
All four tracks are powered hydrostatically, a form of hydraulics where fluid is pumped at high pressure to drive small turbines that act as motors. All four tracks are independently driven.

STEP 2

Elevation
The elevated cab means that the L&RS can launch a boat regardless of tide.

STEP 3

Launch
The boat's launch is under the control of the coxswain, allowing him to get under way as soon as possible.

All images © SuperCat

The Statistics...

Lifeboat Launch and Recovery System (L&RS)

Manufacturer: Supacat

Dimensions: 20.3 x 4.6 x 3.5 metres (66.6 x 15.1 x 11.5 feet)

Weight: 37 tons (approx)

Engine: Scania DC13

Engine capacity: 12.7 litres

Fuel: Diesel

Unit Price: TBA

Status: Pre-production final prototype

INTERVIEW

Simon Turner

Simon Turner is the project engineer for the Supacat L&RS

HIW: What advantages does the L&RS offer over the modified commercial vehicles used to launch lifeboats?

ST: For a start it's a lot less labour-intensive. Currently, launches need about a dozen ground crew, but with the L&RS you can carry out a launch with two or ideally three people – one driver/operator and two directing operations from the ground. The L&RS has dramatically improved launch time and safety. Also the turntable means that not only can a boat be recovered and launched bow first but it can be relaunched quickly.

HIW: The L&RS is packed with electronics. How did you ensure that they would operate safely in water?

ST: It was a big design issue. The whole system has been heavily over-engineered to make it as reliable as possible. All the electrical components are top-quality maritime spec designed to operate at up to 25 metres, rather than the 2.5 metres the launcher would usually operate at. The software and electrics are operated via a Bosch CAN bus (Controller Area Network) system that's very reliable and robust.

HIW: Were the unique features of the L&RS part of the design brief from the RNLI or your own ideas?

ST: A lot of features, including the turntable, were our ideas. We've worked with the RNLI for over ten years on various projects, but nothing as complicated as this. They first approached us with a fairly open brief, asking us about ideas for a lifeboat launcher, and we developed it from there.

Crane ship engineering

How do these colossal lifting devices stay afloat?

Heavy lift crane vessels – such as the Saipem 7000 and SSCV Thialf, the two largest semi-submersible cranes in the world – support colossal weights while remaining stable at sea via an integrated dynamic positioning system – a computerised system that automatically operates the vessel's mooring, ballast and thrusters in sync. This, in partnership with their catamaran-style dual hull structure – a build type that ensures significant stability improvements over traditional monohull vessels by increasing the potential load platform – and semi-submersible design, allow these vast cranes to remain stable in rough seas and under immense uneven loads.

Ballast tanks are key to vessels this size, and as such are installed on most deepwater offshore oil platforms and floating wind turbines too. By locating multiple ballast tanks around the ship's twin hulls, on demand the vessel's centre of gravity can be lowered and the draft (the vertical distance between the waterline and the bottom of the hull) increased. This provides greater stability to these top-heavy lifting platforms but also – as the vessels are designed to be semi-submersible – allows a large part of it to rest below the ocean surface, mitigating the effects of large waves.

A crane ship's mooring systems are extensive, with over a dozen anchor lines positioned around its outer frame. Each line is made up of over 3,000 metres of twisted wire rope, culminating in reinforced chain attached to a 35 ton-plus anchor. The anchor descends and rests at the centre of the vessel, with each of the lines drawn inwards under the vessel. Additional secondary anchors are also carried, often deployed in extremely rough weather conditions or where pinpoint accuracy is necessary.

Working in collaboration with the mooring system are a vessel's thrusters, which are split evenly between hulls. These are distributed at the bow – usually in enclosed tunnels – directly under the hull and at the stern, the latter primarily used when transiting between locales. The thrusters are controlled via the vessel's aforementioned dynamic positioning system, which draws on positional, environmental and gyro compass sensors located around the ship to maintain optimal operational placement.

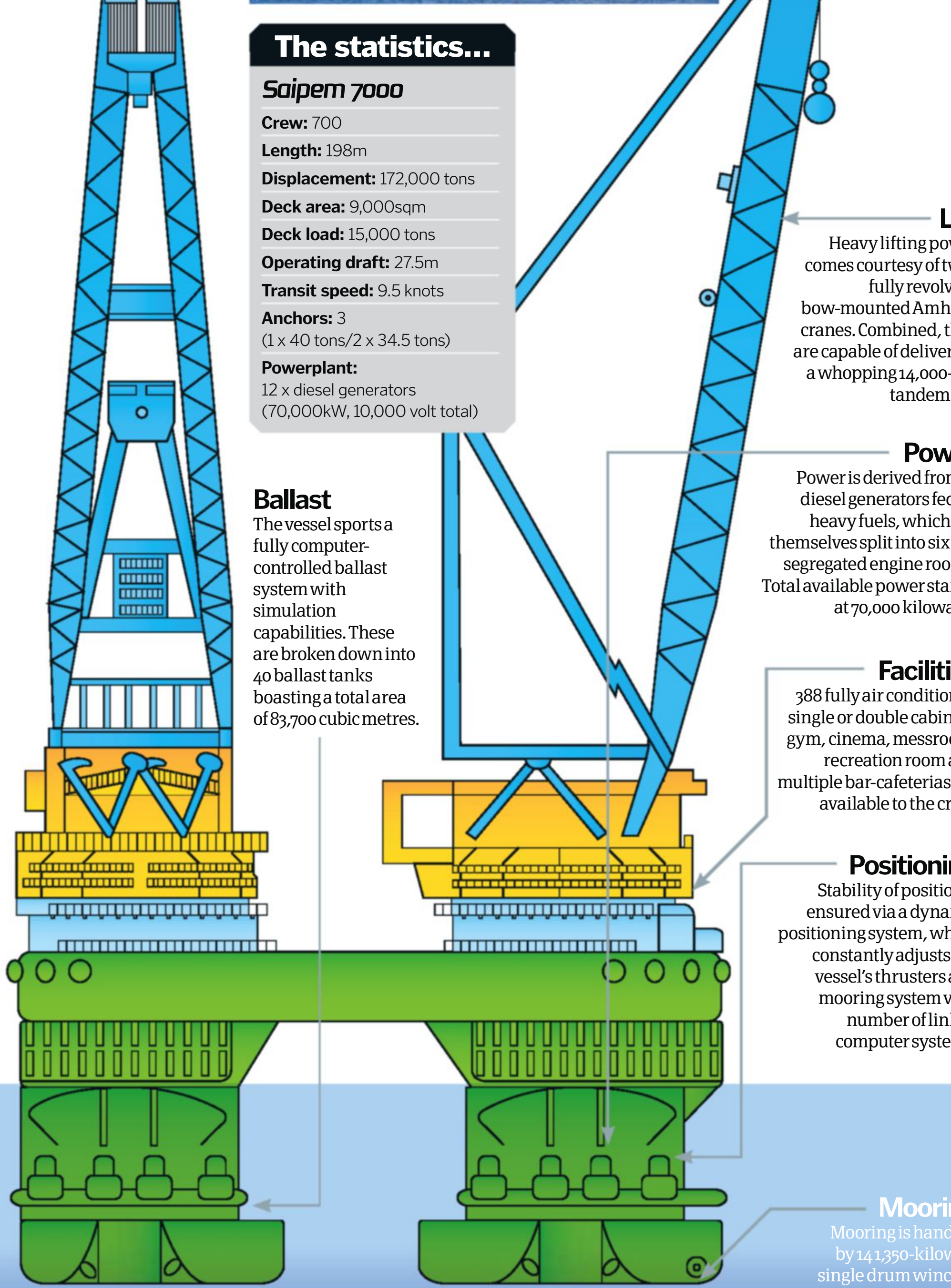
The Saipem 7000 is the second-largest crane vessel in the world

© TeeGeeNo

The statistics...

Saipem 7000

Crew: 700
Length: 198m
Displacement: 172,000 tons
Deck area: 9,000sqm
Deck load: 15,000 tons
Operating draft: 27.5m
Transit speed: 9.5 knots
Anchors: 3
(1 x 40 tons/2 x 34.5 tons)
Powerplant:
12 x diesel generators
(70,000kW, 10,000 volt total)



Lift
Heavy lifting power comes courtesy of twin fully revolving bow-mounted Amhoist cranes. Combined, they are capable of delivering a whopping 14,000-ton tandem lift.

Power
Power is derived from 12 diesel generators fed on heavy fuels, which are themselves split into six fire segregated engine rooms. Total available power stands at 70,000 kilowatts.

Ballast
The vessel sports a fully computer-controlled ballast system with simulation capabilities. These are broken down into 40 ballast tanks boasting a total area of 83,700 cubic metres.

Facilities
388 fully air conditioned single or double cabins. A gym, cinema, messroom, recreation room and multiple bar-cafeterias are available to the crew.

Positioning
Stability of position is ensured via a dynamic positioning system, which constantly adjusts the vessel's thrusters and mooring system via a number of linked computer systems.

Mooring
Mooring is handled by 14 1,350-kilowatt single drum winches in partnership with a 40-ton high holding power anchor and two 34.5-ton anchor windlasses.

Anatomy of a crane ship

How It Works takes a look at the capabilities and construction of one of the world's largest crane ships

Tachometers

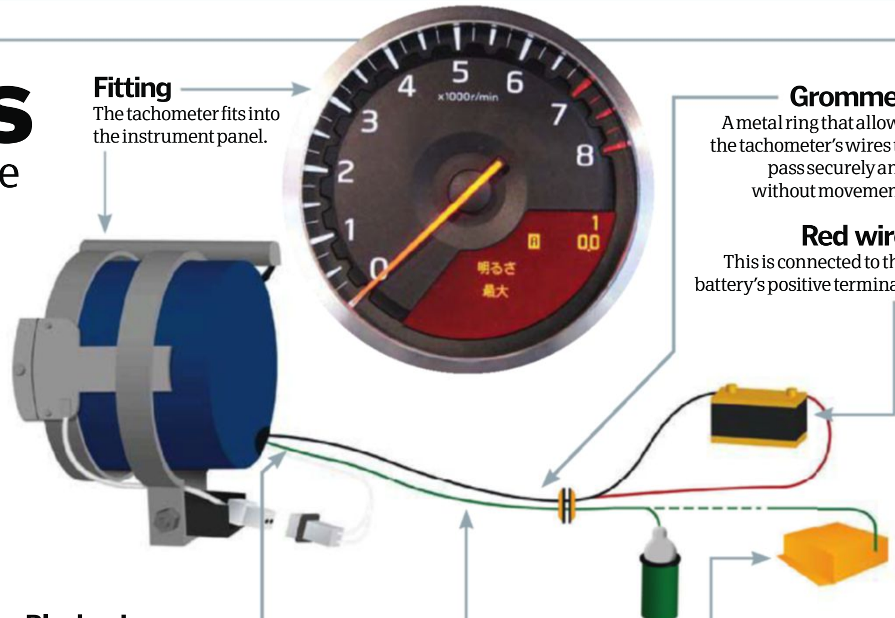
How do rev counters measure the rotation of engines?

A tachometer is a piece of equipment that measures the rotation of the engine crankshaft, and indicates this information on an analogue dial or a digital display.

These readings warn the engine operator/driver when the revs (revolutions) per minute (rpm) of the engine are dangerously high, or if the gear setting or speed of the engine should be adjusted for the prevailing conditions.

The tachometer in a car is often connected to the low-tension side of the ignition coil, which measures the number of ignition discharges to determine the rpm.

Cars with engine control units (ECUs) use a crankshaft position sensor to measure the revs per minute. This consists of a disc on the crankshaft that on each rotation passes a magnetic coil sensor. Every time the disc passes the sensor it disrupts the sensor and this disruption is measured as one rotation. The disruptions are calculated into rpm by the ECU and displayed to the driver.



Fitting
The tachometer fits into the instrument panel.

Grommet
A metal ring that allows the tachometer's wires to pass securely and without movement.

Red wire
This is connected to the battery's positive terminal.

Black wire
The black wire is connected to the negative terminal of the battery and leads to the ground.

Green wire
The green wire leads to either the ignition coil or electronic ignition.

Ignitions
Connection to the vehicle's electronic and standard ignitions provides accurate rpm stats.

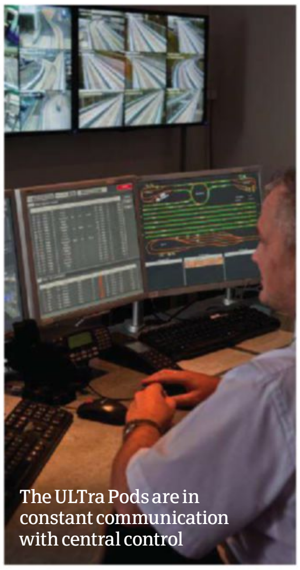
Panelling
The ULTra Pod's body panels are vacuum formed and feature a high-gloss acrylic capping.

Power
ULTra Pod power is stored and delivered in lead-acid batteries, which allow for rapid charging.

Movement
Each pod is fitted with four pneumatic rubber tyres as well as front-wheel steering and damped-spring suspension.

The pods can carry up to four passengers and their luggage

3 x © ULTra PRT



The ULTra Pods are in constant communication with central control

ULTra Pod automated vehicles

Discover the futuristic computer-controlled taxi transport system now in operation at Heathrow Airport

An ULTra Pod system consists of a series of individual pods, each of which can carry up to four passengers and their luggage. Each 850-kilogram (1,870-pound) pod is powered by lead-acid batteries that are recharged at station berths or at special waiting points. They travel on four rubber pneumatic tyres and can reach speeds of up to 40 kilometres per hour (25 miles per hour).

The pods run along a guideway that consists of a 1.6 metre (5.3 feet)-wide flat surface that is bordered on each side by 25-centimetre (10-inch) kerbs.

When passengers select their destination, three levels of control come into operation. First, central synchronous control allocates a vehicle for the specified journey and plots its path and timing. Second, when the autonomous vehicle control system receives instructions from central control it automatically guides the pod using laser sensors through the guideway network. Third, the automatic vehicle protection (AVP) system only allows the pod to move when it receives a 'proceed' signal.

Throughout the journey, the pod is in constant wireless communication with the control centre, but it can operate autonomously if this communication happens to become disrupted.

F-35 AND THE FUTURE FIGHTERS

Legacy aircraft worldwide are being blown out of the skies by a formation of revolutionary multi-role fighter jets, offering all-round air supremacy and a lethal barrage of explosive new technology

5 TOP FACTS
F-35 LIGHTNING II

Birth
1 The F-35 was born out of the joint strike fighter (JSF) programme, which was initiated to create an aircraft that would replace the F-16, A-10, F/A-18 and AV-8B tactical fighter jets.

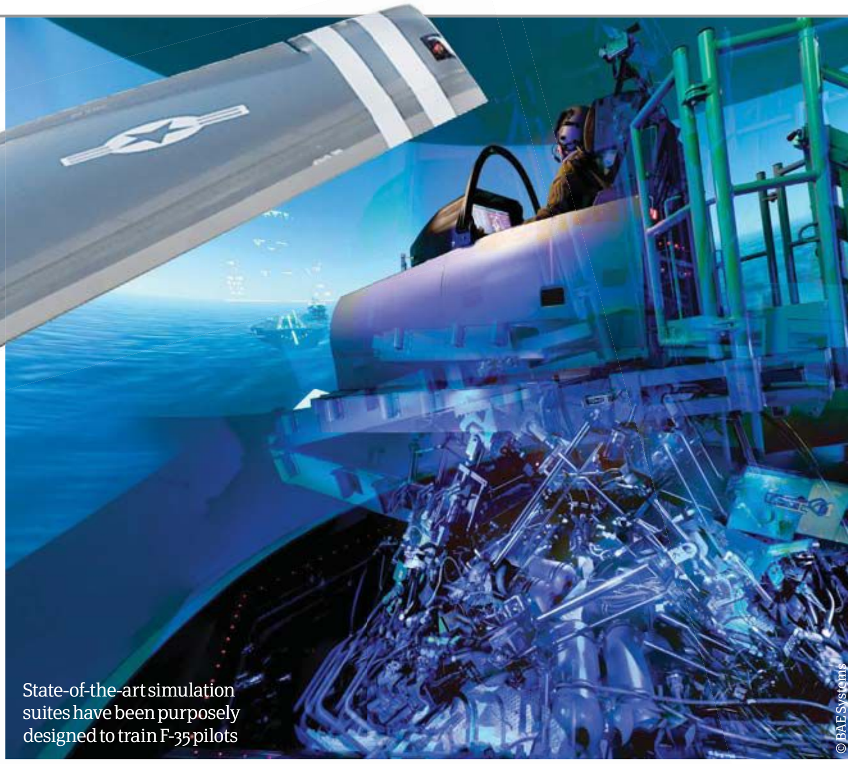
X-35
2 The prototype F-35 was the Lockheed Martin X-35, which narrowly beat a rival design from Boeing (X-32), despite both aircraft exceeding or meeting the JSF requirements.

DoD
3 Interestingly, the F-35 designation of the Lightning II is out of sequence with standard DoD numbering. It was supposed to be named the F-24 instead.

Alliance
4 There are eight global partners in the F-35's development along with the USA: the UK, Italy, the Netherlands, Australia, Canada, Denmark, Norway and Turkey.

LiftSystem
5 The STOVL variant of the F-35 Lightning II uses the Rolls-Royce LiftSystem, an innovative propulsion system that allows for the main engine exhaust to be redirected for vertical lift.

DID YOU KNOW? *Total development costs of the F-35 Lightning II are estimated to have run to $40 billion*


State-of-the-art simulation suites have been purposely designed to train F-35 pilots

© BAE Systems

"Each F-35 utilises structural nanocomposites, such as carbon nanotube-reinforced epoxy"


An F-35 on Lockheed Martin's primary build line at Fort Worth in Texas

© BAE Systems

F-35 Lightning II

Put simply, the most versatile, deadly and technologically advanced fighter jet in the world

The latest and greatest 'black project' from Lockheed Martin's Skunk Works – technically referred to as the Advanced Development Programs (ADP) unit, a classified division of the company unrestrained by bureaucracy – the F-35 Lightning II is the most advanced fighter jet on Earth. It's the first and only stealthed, supersonic, multi-role fighter.

Born out of a demand to dominate the fluid 21st-century battlefield, replacing a plethora of legacy aircraft such as the F-16 and A-10 Thunderbolt II, the F-35 is rewriting the rulebook on aircraft design, capable of performing almost any possible role imaginable today – be that strike, support or reconnaissance – with greater efficiency than any other aircraft made to date. The cost of this performance? £89m ($139m) per plane.

So what does the cash actually buy you? To start, the most powerful powerplant ever fitted to a fighter aircraft. The F-35, across all its three variants – read: F-35A, F-35B and F-35C, differentiated by takeoff mechanism – is fitted with a Pratt & Whitney F135 afterburning turbofan jet engine, which delivers 19,500 kilograms (43,000 pounds) of thrust and grants a top speed of over 1,930 kilometres (1,200 miles) per hour; that's over Mach 1.6 or, to put it another way, infinitely faster than your gran's Mini Metro!

The cash, which is being dropped in large quantities by the States, as well as eight global partners including Britain – which is set to deploy the aircraft on its new Queen Elizabeth-class aircraft carriers – also purchases the operator one of the most advanced aircraft structures in existence. Each F-35 utilises structural nanocomposites, such as carbon nanotube-reinforced epoxy and bismaleimide (BMI), to produce a framework unrivalled in lightness and strength, as well as heavily integrating epoxy glass resin to maximise aerodynamics. In terms of skin and coatings, each F-35 sports a radar cross-section (ie radar signature) the size of a golf ball thanks to the heavy implementation of fibre-mat over the fuselage.

The cockpit is also state of the art, delivering a full-panel-width, panoramic glass cockpit display as well as a host of bleeding-edge avionics and sensors such as the Northrop Grumman AN/APG-81 AESA radar and electro-optical targeting system (EOTS). Further, much of the cockpit has been optimised for speech-recognition interaction, allowing the pilot to control many parts of the jet by voice alone.

Of course, the main attraction of the Lightning II is its diverse armaments – the equipment that transforms it from technical marvel into a master of destruction. You want air-to-air prowess? You've got it, with the F-35 capable of launching AIM-120 AMRAAMs, AIM-9X Sidewinders, IRIS-Ts and the futuristic beyond-visual-range MBDA Meteor. For maximum air-to-ground penetration, take your pick from AGM-154 JSOWs, SOM Cruise Missiles and Brimstone anti-tank warheads. Even if you want to engage marine-based targets the F-35 delivers the goods, capable of launching the new anti-ship Joint Strike Missile (JSM). Throw in a raft of other munitions, including the Mark 80 series of free-fall bombs, Mk.20 Rockeye II cluster bomb, the Paveway series of laser-guided bombs and even, in DEFCON 1 situations, the B-61 nuclear bomb and you have one extremely versatile and deadly feat of aviation. ▶

The rate of climb of the F-35 is currently classified

© BAE Systems

Anatomy of the F-35 Lightning II

We break down this awesome piece of military engineering to see what makes it so advanced

LiftSystem

Made by tech-masters Rolls-Royce, the F-35's LiftSystem is an innovative propulsion system that allows for the main engine exhaust to be redirected for direct vertical lift. Perfect for carrier deployment.


© BAE Systems

Cockpit

A panoramic glass cockpit display (PCD) is standard on the F-35, allowing unparalleled visibility. Speech-recognition systems also offer audio control of parts of the pilot interface.


© BAE Systems

Sensors

The main sensor installed in the F-35 is an AN/APG-81 AESA radar, which is produced by Northrop Grumman. This main radar is augmented with an electro-optical targeting system (EOTS) mounted under the nose.

Armament

Asides from a stock GAU-22/A quad-barrelled cannon, the F-35 can carry a wide variety of bombs and missiles, ranging from AIM-9X Sidewinders, through AGM-128s and on to JDAM-guided bombs.

History of multi-role fighter jets

The F-35 is the culmination of more than 30 years of development into producing a single, king-of-all-trades fighter plane

1979 Panavia Tornado

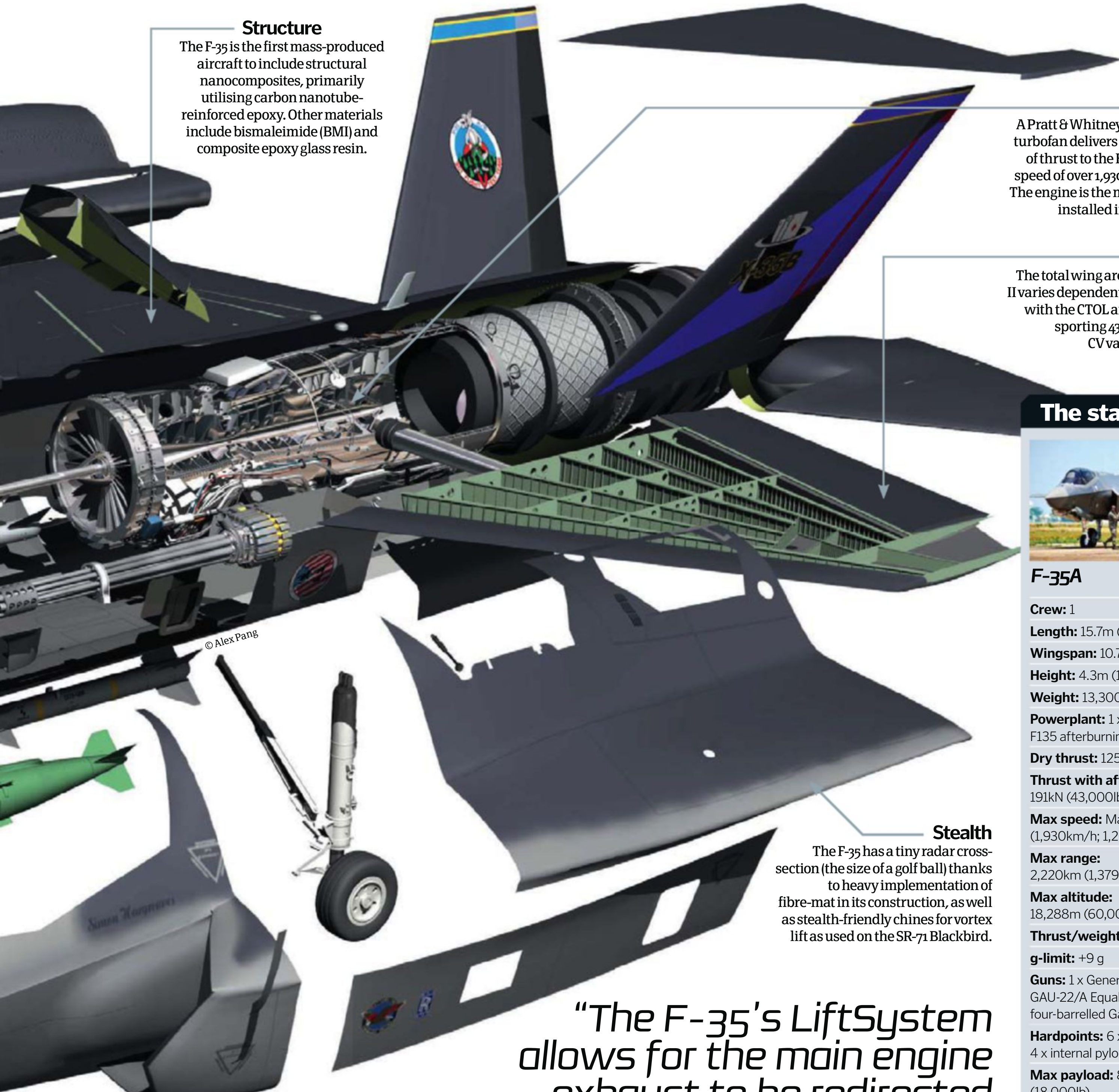
The first multi-role fighter to be produced, the Tornado – across its three variants (each providing differing abilities) – offered its owner the best of striker, bomber, interceptor and reconnaissance aircraft.

1983 McDonnell Douglas F/A-18 Hornet

Maybe the most recognisable multi-role fighter until the F-22, the Hornet was an all-weather, carrier-capable fighter specialising in short/medium-range bombing ops.

1988 JAS-39 Gripen

Another early delta-wing, multi-role fighter, the Gripen was designed to be incredibly lightweight for a fighter and sported impressive air-to-ground bombing capabilities. It has recently been upgraded for continued use.



Structure

The F-35 is the first mass-produced aircraft to include structural nanocomposites, primarily utilising carbon nanotube-reinforced epoxy. Other materials include bismaleimide (BMI) and composite epoxy glass resin.

Powerplant

A Pratt & Whitney F135 afterburning turbofan delivers 19,500kg (43,000lb) of thrust to the F-35, allowing a top speed of over 1,930km/h (1,200mph). The engine is the most powerful ever installed in a fighter aircraft.

Wings

The total wing area of the Lightning II varies dependent on configuration, with the CTOL and STOVL variants sporting 43m² (460ft²) and the CV variant 62m² (668ft²).

Stealth

The F-35 has a tiny radar cross-section (the size of a golf ball) thanks to heavy implementation of fibre-mat in its construction, as well as stealth-friendly chines for vortex lift as used on the SR-71 Blackbird.

"The F-35's LiftSystem allows for the main engine exhaust to be redirected for direct vertical lift"

The statistics...

F-35A

Crew: 1

Length: 15.7m (51.4ft)

Wingspan: 10.7m (35ft)

Height: 4.3m (14.2ft)

Weight: 13,300kg (29,300lb)

Powerplant: 1 x Pratt & Whitney F135 afterburning turbofan

Dry thrust: 125kN (28,000lbf)

Thrust with afterburner: 191kN (43,000lbf)

Max speed: Mach 1.6 (1,930km/h; 1,200mph)

Max range: 2,220km (1,379mi)

Max altitude: 18,288m (60,000ft)

Thrust/weight: 0.87

g-limit: +9 g

Guns: 1 x General Dynamics GAU-22/A Equalizer 25mm four-barrelled Gatling cannon

Hardpoints: 6 x external pylons, 4 x internal pylons

Max payload: 8,100kg (18,000lb)

Armament: Air-to-air, air-to-ground, anti-ship

© MOD Czech Republic

1996 Sukhoi Su-30

© Sergey Krivchikov

Envisioned as a fighter jet with excellent air-to-surface deep interdiction prowess (the ability to strike hostile targets at extreme range from friendly forces), the Russian Su-30 typifies multi-role designs from the mid-Nineties.

2000 Dassault Rafale

Marketed by Dassault as an 'omnirole' jet, the Rafale was an agile delta-wing fighter, specialising in air supremacy. A collapse in a multi-nation agreement, however, led it to be used for other roles by France and India.

2005 Lockheed Martin F-22 Raptor

Originally conceived as an air superiority fighter, the F-22 evolved over time into a multi-role jet, capable of ground attack and electronic warfare roles thanks to its extremely low radar cross-section.

© Rob Shenk

According to government officials, the T-50 will have a low radar cross-section and have the ability to supercruise (perform sustained supersonic flight)

© Maxim Maksimov

Sukhoi T-50

Russia's hottest jet project currently in development, the highly classified Sukhoi T-50 is a fifth-generation multi-role fighter designed to deliver awesome long-range strike capabilities

Arguably the main competitor to the F-35 Lightning II, the Russian-made Sukhoi T-50 is an extremely advanced, twin-engine, multi-role jet fighter that, aside from being a top-level black project (in other words, highly hush-hush), promises to deliver an insane top speed, range and payload.

Power, which is titanic – 267 kilonewtons (66,000 pounds-force) of thrust on afterburner – comes courtesy of two Saturn 117 turbofan jet engines. The thrust has been drastically increased since the previous AL-31 powerplant and this not only allows the T-50 to easily surpass Mach 2 (a top speed of 2,500 kilometres, or 1,500 miles, per hour) but also supercruise – continuously fly at supersonic speeds without engaging the afterburner.

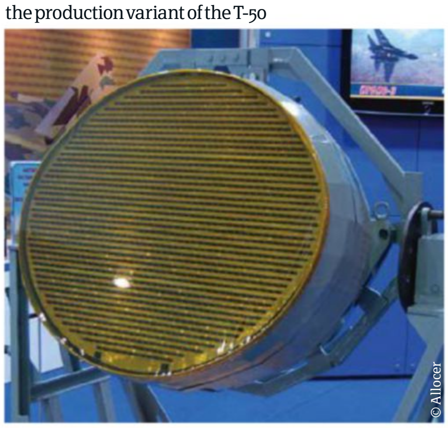
The reason for the twin-engine setup, as well as the supersized fuel tanks, is to help fulfil the T-50's design focus to specialise in long-range interdiction operations (striking at enemy targets that are located at a great range from allied forces). This is a core competency for modern Russian military bombing aircraft due to the size of the country and the great distances between stopover points.

Avionics are handled by an integrated radar complex, which includes three X-band active electronically scanned array (AESA) radars mounted to the front and sides of the aircraft, an infra-red search and track (IRST) system, as well as a pair of L-band radars on the wing leading edges, which are specially designed to detect very low observable (VLO) targets.

In terms of firepower, the production variant of the T-50 will boast up to two 30-millimetre cannons, as well as a mix of Izdeliye 810 extended-beyond-visual-range missiles, long-range missiles, K74 and K30 air-to-air short-range missiles and two air-to-ground missiles per weapons bay. Free-fall bombs can also be carried – with a limit of up to 1,500 kilograms (3,300 pounds) per bomb bay – as well as various anti-AWACS (airborne warning and control system) armaments, such as the RVV-BD variant of the Vympel R-37.

Currently only a handful of T-50s have been produced and flown, however it is expected that throughout its 35-year life span beginning in 2016, more than 1,000 jets will be made, each unit costing between £31-36m ($48-57m).

The NIIP AESA radar as will be used on the production variant of the T-50



© Allocer

As well as air-to-air roles, the Typhoon can adapt to air-to-ground operations, delivering GBU-16 Paveway II bombs

The statistics...

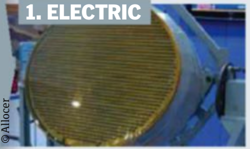
© Dmitry Pichugin

Sukhoi T-50

Crew: 1
Length: 19.8m (65.9ft)
Wingspan: 14m (46.6ft)
Height: 6.05m (19.8ft)
Weight: 18,500kg (40,785lb)
Powerplant: 2 x AL-41F1 afterburning turbofans
Max speed: Mach 2+ (2,500km/h; 1,560mph)
Max range: 5,500km (3,417mi)
Max altitude: 20,000m (65,600ft)
Rate of climb: Classified
Thrust/weight: 1.19
g-limit: Classified
Guns: 2 x 30mm cannons
Hardpoints: 6 x external pylons, 4 x internal pylons
Armament: Air-to-air, air-to-ground, anti-ship

Head to Head
FIGHTER JET ROLES

1. ELECTRIC



Electronic warfare
Some jets use specialised equipment to control, disrupt or attack enemy targets with a host of cutting-edge electromagnetic weaponry.

2. CLOSE CALL

Close air support
Supporting ground troops with air action despite their close proximity. Achieved with fixed-wing or rotary aircraft.

3. LONG DISTANCE

Air interdiction
This role involves using aircraft to attack tactical ground targets that are not currently in close proximity to ground forces but located at a considerable range.

DID YOU KNOW? *The Sukhoi T-50 is expected to be renamed to the Sukhoi PAK FA when it is officially launched in 2016*

Eurofighter Typhoon

The Typhoon is one of the most adaptable multi-role fighters in operation today and has recently been upgraded to deliver enhanced air superiority and all-round lethality in its combat operations over the next decade

The Eurofighter Typhoon is currently one of the most agile aircraft in the world. It is so agile, in fact, that attempting to blow it out the skies is like trying to make a mile-long sniper shot in high wind. Why? It was built to be fundamentally aerodynamically unstable and, if it were not for its advanced fly-by-wire control system generating artificial stability, would be too much for even the most experienced pilot to handle. This instability, however, allows for pilots to perform some physics-bending manoeuvres at just plain stupid speeds – read: upwards of Mach 2 – delivering them a combative edge and helping to ensure total air supremacy.

Of course, agility alone can only take you so far – especially so when the hardware needs to fulfil almost every airborne military role imaginable. Good job then that the Typhoon can carry an abundance of weapons. You need to go toe-to-toe with enemy fighters in an air-to-air combat dogfight? No problem, take your pick from Sidewinder, ASRAAM and AMRAAM air-to-air missiles. Need to undertake a bombing run through hostile territory? Well, the Typhoon's 13 hardpoints allow for Maverick, HARM and Taurus munitions to be smartly delivered (via laser-guiding and GPS) with ice-cold efficiency. Need to disrupt a hostile target's comms network through a tactical electronic warfare strike… You get the point.

Supporting this awesome arsenal is an upgraded weapons system, which has been designed to unite the pilot and hardware like never before. Typhoon pilots are now linked to their aircraft by an 'electronic umbilical cord', which extends from a comms-optimised helmet directly into the jet's system. This not only allows images and videos of notable contextual information to be directly fed to the helmet's visor for immediate consultation by the pilot, but also enables special nodules on the helmet to be tracked by fixed sensors in the aircraft's cockpit. As such, wherever the pilot's head moves, the aeroplane knows exactly where they are looking and can automatically prep weapon stores dependent on the perceived level of threat.

Any future fighter though also needs to be prepared to defend itself against a barrage of smart munitions, which again – thanks to the Typhoon's perpetual evolution – the hardware delivers in spades. The entire jet is protected by a high-integrated defensive aids sub-system (DASS), also nicknamed Praetorian. Praetorian consists of a wide array of sensors and electronic/mechanical systems – detection is handled by both a radar warning receiver and laser warning receiver – that automatically track and then respond to both air-to-air and surface-to-air threats. The plane can respond by releasing chaff (eg small bits of aluminium or metallised glass, etc), flares and electronic countermeasures (ECM), as well as by releasing a towed radar decoy (TRD).

As of October 2011, 300 Typhoons are recorded to be in operation worldwide with over 170 aircraft on order.

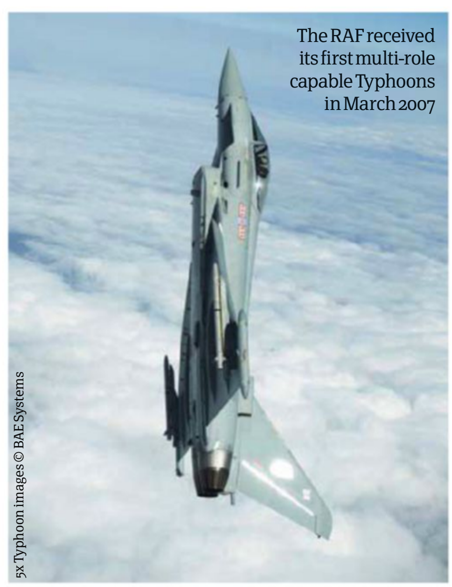
"The Typhoon's 13 hardpoints allow multiple munitions to be smartly delivered with ice-cold efficiency"

The statistics…

Eurofighter Typhoon

Crew: 1
Length: 16m (52.4ft)
Wingspan: 11m (35.9ft)
Height: 5.3m (17.3ft)
Weight: 11,150kg (24,600lb)
Powerplant: 2 x Eurojet EJ200 afterburning turbofans
Dry thrust: 60kN (13,000lbf) each
Thrust with afterburner: 89kN (20,000lbf) each
Fuel capacity: 4,500kg (9,900lb) internal
Max speed: Mach 2+ (2,495km/h; 1,550mph)
Max range: 3,790km (2,350mi)
Max altitude: 19,810m (64,990ft)
Rate of climb: >315m/s (62,000ft/min)
Thrust/weight: 1.15
g-limit: +9/-3 g
Guns: 1 x 27mm Mauser BK-27 revolver cannon
Hardpoints: 13 (8 x under-wing, 5 x under-fuselage)
Max payload: 7,500kg (16,500lb)
Armament: Air-to-air, air-to-ground, anti-ship

A Typhoon undertakes a low pass at high speed



The RAF received its first multi-role capable Typhoons in March 2007

How do sails work?

Appearing simple in form and function, sails are in fact complicated and refined pieces of technology, made from specialised materials to maximise propellant force and stability

Sails work in two ways. The first is simply by trapping the wind in their material as it flows by, an action that leads the sail to become aerodynamically stalled. This, however, only happens when a vessel is sailing directly downwind. The second and far more common way is by acting like a giant vertical airfoil in order to generate areas of higher and lower pressure to manipulate and harness environmental wind as a propellant force. This works as when a fluid – such as air or water – passes over the top surface of an airfoil (the shape of a sail or wing of an aircraft) it is accelerated due to its flow angle. As a consequence of this acceleration, the pressure the air imparts on the sail's adjoining surface decreases, pulling upwards on the surface and creating lift and momentum. It is this principle that enables experienced sailors to adjust a vessel's sail in order to drive forwards, even into a head wind.

Sail construction also plays a large part in their ability to propel a vessel. Indeed, a sail's material, rigging type and overall shape and rigidity each accounts for how fast a boat can move as well as its stability. Traditionally, sails were constructed from flax and cotton, however nowadays they are predominantly made from synthetic materials such as nylon and Vectran. These materials are light, durable and resistant to stretch – something that has a detrimental effect to propellant speed and general sail efficiency.

These modern sails can be rigged in two main ways: in a square or a fore-and-aft arrangement. Square rigging – common in the late 19th and early 20th centuries – is a layout where sails are mounted at a right angle to the keel of the vessel. This rig grants the vessel great potential forward momentum, however it cannot sail closer than roughly 60 degrees to the wind and can only generate momentum on one side of any sail. In contrast, the more modern fore-and-aft rig offers the ability to generate pressure differentials on each side of the sail. This grants much more flexibility to manipulate changing wind directions and flows, at the expense of some of the raw forward thrust generated by square-rigged sails in optimal conditions.

Finally, a sail's overall shape considerably affects its performance. There are six classes of primary sail, including: gaff, jib-headed, square, spirit, lug and lateen sails, each providing different handling, stability and speed.

STRONG

1. Horse
Originally horsepower was designed to compare the power of draught horses and steam engines. One horsepower equals about 736 watts.

STRONGER

2. TA300
The TA300 articulated dump truck has a 287-kilowatt (385-horsepower) engine and can carry up to a 30-ton load.

STRONGEST

3. The Edward J Moran
One of a very powerful series of tugboats, with a 4,848-kilowatt (6,500-horsepower) twin engine, it can haul up to 94,000-ton vessels.

DID YOU KNOW? 40mm windscreen cracks can be repaired, but in the 'A- zone' in front of the driver, only 10mm faults can be fixed

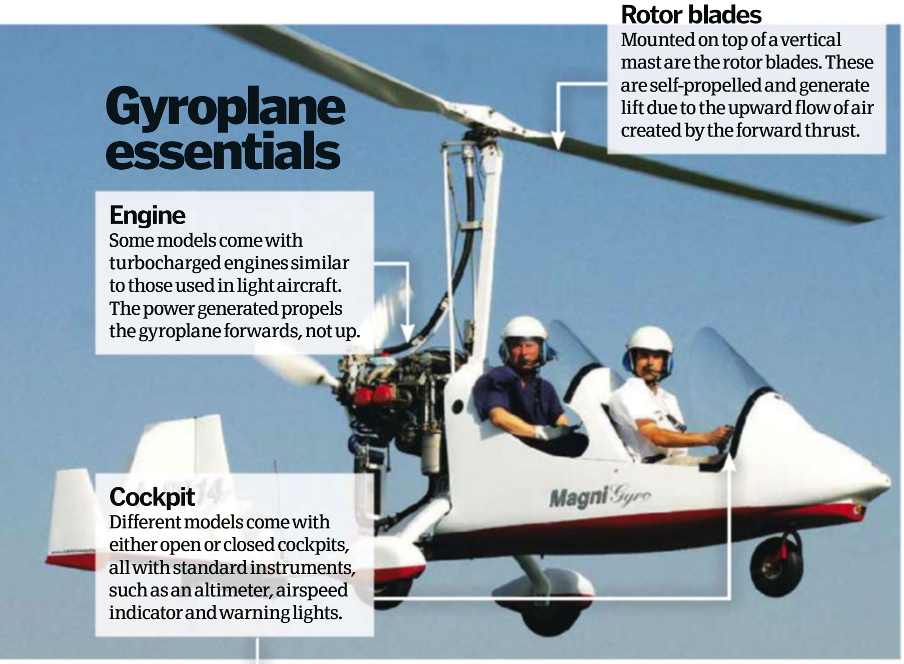
How does a gyroplane work?

The plane that likes to think it's a helicopter explained

While a gyroplane may look like a small helicopter, it has a lot more in common with a light aircraft. Unlike a traditional chopper, the freely rotating blades atop a gyroplane generate lift without the help of a powered engine. Instead the blades are self-powered by the air that flows over them – this is called autorotation. The spinning blades enable the vehicle to ascend, descend or remain level during flight.

Gyroplanes do indeed have an engine to power a forward or rear-facing propeller, but the thrust provided is used to propel the gyroplane forwards, rather than power the rotor blades. The forward movement creates an upward airflow through the rotor blades from beneath; this in turn causes the blades to turn, generating lift.

Although these vehicles might appear rather insecure, gyroplanes are in fact very safe. If for some reason the engine were to fail, the force of the wind through the rotor blades would keep them spinning at the same speed regardless.



The rotating blades create an upward force, unlike on a helicopter

A tugboat pulls a massive freighter into Hamburg Port, Germany

Tugboat power explained

Discover why the smallest ships are also often the strongest

Tugboats have a 507-2,535-kilowatt (680-3,400-horsepower) engine, which can grant them a power-to-weight ratio of up to 4.50. This is a measure of the sheer brute force of an engine, worked out by dividing the engine's power by the weight of the vehicle. It's also a mark of how extraordinarily strong tugboats are, relative to their size, given that the power-to-weight ratio of the much bigger ships they tow varies between 0.30 and 1.20.

The key to a tugboat's success lies in how it utilises this strength. Z-drive propellers are designed to rotate 360 degrees so that the tug can change direction on the spot. Similarly, the Voith Schneider Propeller (VSP) system often employed uses a series of blades whose angle can be altered so they can provide thrust in any direction, once again allowing the tug to haul or push its charge into any position.

How tractors work

Fitted with air-conditioned cabs, on-board computers and GPS, these workhorses now offer brains and brawn

Tractors can operate a huge range of machinery due to their built-in features such as three-point linkage and power takeoff (PTO). The three-point linkage mounted on the rear of a tractor is used to lift and operate machinery including those that need to function at varying heights/depths, such as ploughs and bulldozer-like scraper blades for mucking out. The three-point linkage comprises two parallel, hydraulically powered lifting arms with the third non-powered arm forming the apex of a triangle. The two lifting arms have hollow ball sockets in their tips that fit over fixed lifting bolts protruding from the item of machinery they are picking up. These are fixed with split pins through holes in the bolts. The third arm acts as a stabiliser and is secured with a nut-and-bolt connection. This triangle configuration is seen in engineering as the strongest way to secure two objects.

Three-point linkage lifting power can vary according to tractor size. Below the three-point linkage is the power takeoff. The PTO is an external drive shaft for powering machinery, and is driven through a clutch from the main gearbox and transmission; it's connected to machinery with a drive shaft via a flexible universal joint. The earliest tractors had a powered flywheel rather than a PTO which worked with a belt drive.

PTOs can power equipment from concrete mixers, pump-operated liquid fertiliser spreaders, auger-operated solid fertiliser spreaders and powered grass cutters. Tractors can also power external hydraulics on machinery such as the hydraulic rams on tipper trailers and larger ploughs, which travel on road wheels and then have to be lowered to operate in a field. A machine's hydraulics system is connected to a tractor through hydraulic hoses (basically tough industrial hose pipes) to connectors on the tractor just above the three-point linkage. The tractor then powers the hydraulics using a specialised pump and fluid reservoir.

The biggest advance in tractors in recent years has been the use of GPS, computers and electronic engine management. Tractor steering can be controlled automatically by GPS, so they plough in straight lines, follow crop rows, or turn to a set pattern keeping the 'headland' (the area at the ends of fields where a tractor turns round) as small as possible. A headland isn't properly cultivated so keeping it as small as possible makes maximum use of the land.

Fields can be electronically mapped using GPS and the soil tested. Once the soil has been analysed, the amount of fertiliser can be adjusted depending on the soil quality in different areas of a field. This information can be stored on a tractor's computer (the most advanced tractors have touchscreen displays in the cabs) or even sent via Wi-Fi to a tractor from the farm office. This electronic mapping has other applications too, such as when planting seeds or calculating the depth at which to operate a plough.

GPS tech is used to ensure the tractor operates at optimum efficiency

Big wheels

One of the most noticeable features of a tractor is its huge back wheels, which provide as much surface area between the tractor and the ground as possible. The more surface the greater the tractive power. Traditionally tractors have had much smaller front wheels to provide a tighter turning circle, and with two-wheel drive going through the rear wheels, getting traction through the front wheels hasn't been so important. Nowadays tractors have become more specialised. With smaller tractors often two-wheel drive is employed for working in the farmyard, while larger models – known as field tractors – often use four-wheel drive with more equally sized tyres.

Steering
This model comes with power-assisted steering, while a GPS-controlled system ensures the tractor covers every inch of a field, for optimum coverage when spreading fertiliser etc.

Power
8000 series tractors are powered by an 8.5l (2.2-gallon) diesel engine producing up to 310hp and 1,500N torque at 1,400 rpm.

Front linkage
The 8000 series has optional front-mounted three-point linkage and power takeoff (PTO).

Suspension
The four-wheel Fastrac is the only tractor on the market with all-round suspension – one of the factors that enables it to operate at high speed.

5 TOP FACTS TRACTOR TRIVIA

Biggest
1 Big Bud was a 45-ton, custom-built tractor that had a 3,785 litre (1,000-gallon) fuel tank. With its unique plough, Bud could work 364 hectares (900 acres) in a single day.

Most powerful
2 The US 600hp Case Steiger is the world's most powerful production tractor. The Steiger can come either wheeled or fitted with four individual steered and powered tracks.

Fastest
3 The JCB Fastrac series of tractors (examined in detail below) currently offers the world's fastest production tractors, boasting a top speed of 70km/h (43mph).

Lamborghini
4 Supercar manufacturer Lamborghini started out building tractors. Lamborghini tractors are still made but the tractor company is completely separate from the carmaker.

Hydrogen power
5 Tractor maker New Holland has developed a prototype hydrogen-powered tractor. It's hoped farmers will be able to produce their own renewable energy sources in the near future.

DID YOU KNOW? *Ford manufactured the world's first mass-produced tractor, the Model F, which was launched in 1916*

Inside the JCB Fastrac

Launched in 1991 the JCB Fastrac range lives up to its name with a top speed of 70km/h (43mph). JCB tractors are four-wheel drive and the latest version of the 8000 series has a three-mode electronic gearbox and GPS autosteer

Dashboard
A state-of-the-art touchscreen covers a range of tasks/functions including PTO control, GPS activation and even cruise control.

Joystick
Joystick control is used for functions such as PTO and the electronic gearbox.

Hydraulics
These are the hydraulic connectors for external hydraulics. The 8000 series has a 150 litre (40-gallon) hydraulic fuel reservoir.

Rear linkage
The powerful rear three-point linkage can lift up to 10,000kg (22,046lb).

Power takeoff
The rear PTO produces up to 272hp at 1,000 rpm.

Mid-mounted cab
A mid-mounted cab reduces jolts and improves the driver's view compared with the traditional design in which the cab is located directly over the rear wheels.

Taking the strain

The amazing pulling power of tractors

For all their modern advances tractors would be useless if they couldn't carry out their primary function of moving heavy loads over rough ground. To do this tractors produce huge amounts of torque and traction. Torque is the power produced when rotating a shaft – for instance, the power your legs produce when turning a bicycle's pedals can be measured as torque. Tractors have to produce large amounts of torque (measured in newtons) at low speeds so tractor engines are designed to operate at slow revolutions per minute. This is why in horsepower terms tractors can seem underpowered compared with, say, cars. Horsepower is calculated by multiplying an engine drive shaft's torque power by its rpm, so a 100hp motorbike would produce most of its horsepower through its high rpm, whereas a 100hp tractor produces most of its power as torque. Tractor horsepower is usually calculated from the PTO.

A jack of all trades, the Humvee can be configured to perform many roles

© AM General

A snorkel and raised exhaust make the Humvee a great amphibious vehicle

The Humvee

The high-mobility multipurpose wheeled vehicle (HMMWV) roars off the production line ready for action

Designed to replace several outdated American military vehicles, the high-mobility multipurpose wheeled vehicle, or Humvee, has been in production since 1985. Originally intended as a light utility vehicle, there have been more than 20 variants of this highly customisable, modular platform. Serving over 40 nations, around 200,000 Humvees have been built to date. Able to carry and deploy almost anything, from fully armed troops to anti-aircraft missiles, the Humvee is an open-topped scout vehicle, an armoured personnel carrier, ambulance, a TOW missile launcher, a communication centre, a heavy machine gun platform and whatever else the situation requires.

The latest models are unrivalled in their off-road capability, and are based around a 6.5-litre (1.7-gallon) V8 Turbo diesel engine which produces 142 kilowatts (190 brake horsepower) and 515 Newtons per metre (380 pounds force per foot) of torque. This power is sent to all four wheels through an electronically controlled four-speed automatic gearbox, using a series of differentials. The drivetrain is rather unconventional as the wheels themselves contain portal-geared hubs, which not only double the torque generated, but due to the offset driveshaft inputs, enable the vehicle's ground clearance to be significantly higher than a regular centre axle would allow. This innovative drivetrain, coupled with independent suspension and 94-centimetre (37-inch) tyres, allow the Humvee to travel at 113 kilometres (70 miles) per hour or to climb slopes of 60 per cent – though some Humvees have been seen to climb near-vertical walls! The internal environment is fully air conditioned, while a deep-water fording kit allows the vehicle to cross rivers almost completely submerged. These capabilities, combined with design features such as the sturdy chassis, corrosion resistance plus high commonality and interchangeable parts, enable the Humvee to be flexible, dependable and rugged even in the harshest of environments.

The turret can be fitted with weapons for all kinds of combat situation

© AM General

Armour options

Since the Humvee was introduced, soldiers have demanded increasingly more protection from it. Early versions had fabric doors and no roof, but the demands of Somalia, Iraq and Afghanistan demonstrated the need for improved armour. Many improvised solutions have been tried in the field in recent years, including sandbags and welding scrap metal to the chassis. However, heavily armoured versions are now available from the factory, as are retrofit kits, which include under-body plates, heavy doors, armoured seats, weapon shields and many other additions. The latest iterations offer the crew protection from assault rifle bullets, some air-burst artillery, and up to 5.4 kilograms (12 pounds) of explosives, thanks to thick steel armour, energy-absorbing coatings and mounting, and reinforced glass. All of this comes at a price, though, with many Humvees carrying 907-1,814 kilograms (2,000-4,000 pounds) of armour, which can only be taken in place of cargo and equipment. Work is underway to make the Humvee more resistant to buried explosives, as the large flat floor is not effective against these.

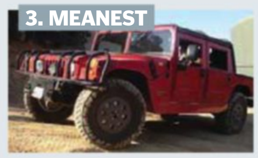
1. MEAN

Willys Jeep
Released at the end of WWII in 1945, the civilian version of the military vehicle was updated regularly and is still on sale to this day.

2. MEANER

Land Rover Defender
Still used by the British armed forces today, the Land Rover Defender is based on the original 1948 Land Rover.

3. MEANEST

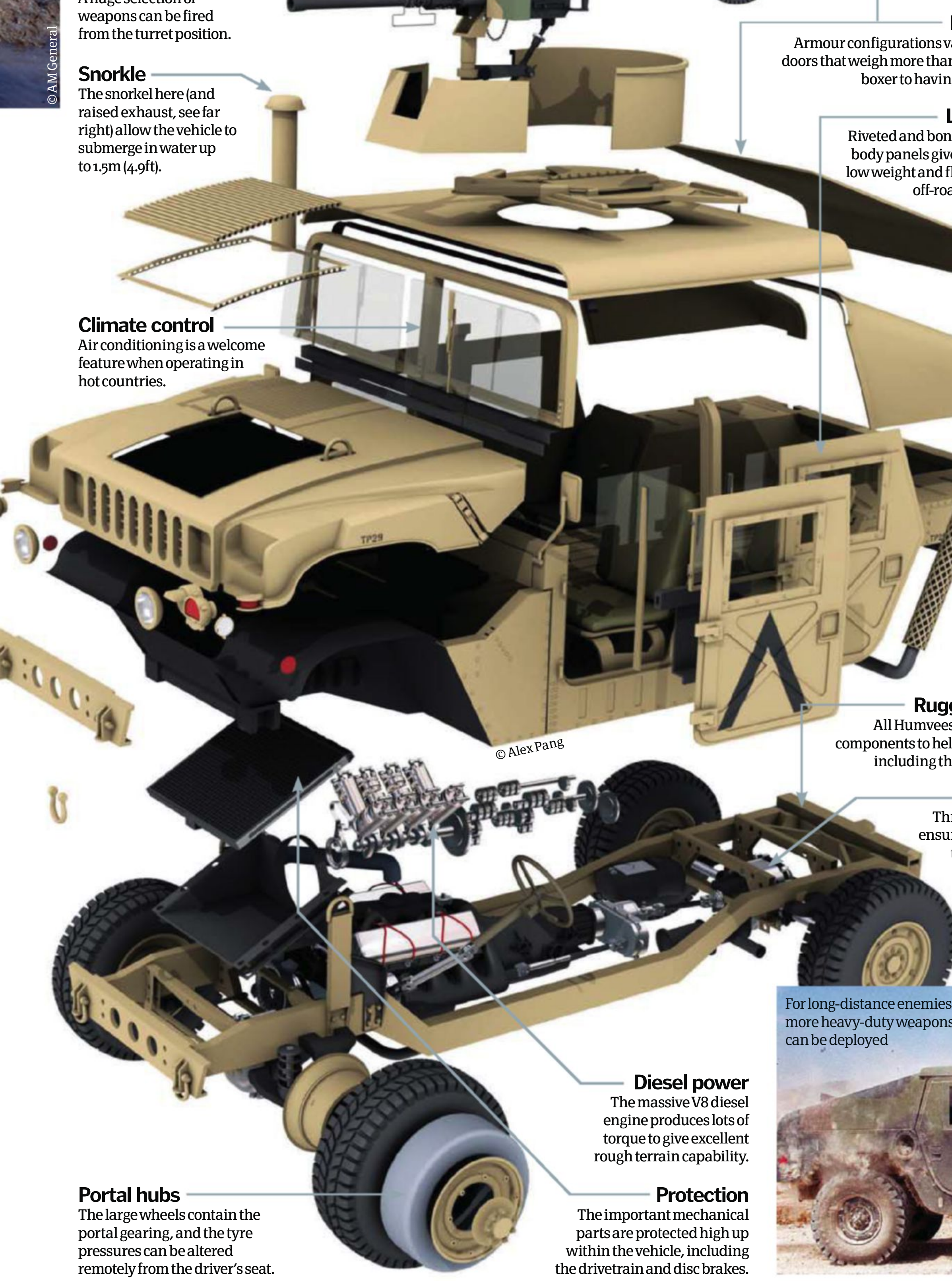


Hummer H1
Also built in the HMMWV factory, the main difference between this beast of a civilian truck and the military version is the colour.

DID YOU KNOW? *Arnold Schwarzenegger was so impressed with the Humvee, he insisted AM General sold him one*

Inside the Humvee

We tear down one of these tough vehicles to find out what makes it so well suited to off-road combat



Weapon turret
A huge selection of weapons can be fired from the turret position.

Snorkle
The snorkel here (and raised exhaust, see far right) allow the vehicle to submerge in water up to 1.5m (4.9ft).

Climate control
Air conditioning is a welcome feature when operating in hot countries.

Hard target
Armour configurations vary from having doors that weigh more than a heavyweight boxer to having no doors at all.

Lightweight
Riveted and bonded aluminium body panels give good strength, low weight and flexibility to help off-road performance.

Rugged chassis
All Humvees share common components to help serviceability, including the chassis frame.

4x4
Three differentials ensure power goes to the wheels at all times, giving great traction.

Diesel power
The massive V8 diesel engine produces lots of torque to give excellent rough terrain capability.

Protection
The important mechanical parts are protected high up within the vehicle, including the drivetrain and disc brakes.

Portal hubs
The large wheels contain the portal gearing, and the tyre pressures can be altered remotely from the driver's seat.

Packing a punch

There was always a requirement to arm the Humvee to provide fire support and self-defence, but the variety of weapons it can carry is astonishing. Starting with a choice of general-purpose machine guns, most weapons can be fired manually or fitted to the remotely operated CROWS turret system. The most common weapon choice is the legendary M2 Browning .50 Calibre. However, should there be a need to raze everything in sight to the ground, the gunner can unleash 100 shots per second using the awesome M134 minigun. For even bigger bangs, the 40-millimetre (1.6-inch) grenade machine gun can launch 60 high-explosive grenades per minute. Should an enemy bring a tank to the fight, the Humvee can launch the TOW anti-armour missile from 3.8 kilometres (2.3 miles) away, or in situations requiring a little bit of overkill, the Humvee is designed to tow a Howitzer cannon. The ultimate version, however, has to be the Boeing-developed Avenger, which carries up to eight stinger anti-aircraft missiles, with proposals for additional weapons including a one-kilowatt laser.

For long-distance enemies more heavy-duty weapons can be deployed

© Sergio Echeverria Garcia

The CL-215 can drop 500 litres of water in one go

Canadair CL-215

Explore this exploded view of the impressive Scooper and its main components

Doors
The four underbelly doors can drop the water all at once or in any sequence the pilot dictates.

Pontoon
Air-filled pontoons enable the plane to stay buoyant and stable on water.

Mixer
Water on its own is not enough, so the Scooper carries additional fire retardant chemicals to mix with each load.

Water bombers

How to fight fires from the sky

Aerial fire-fighting aircraft are similar in operation and tactics to military bombers of World War II. Airfield-based water bombers are prepared with their 'bomb-load' of as much as 78,000 litres (20,500 gallons) of water and chemicals before takeoff. Amphibious aircraft like the Canadair CL-215 'Scooper' are able to operate from local lakes, but often begin the mission at airfields with just a retardant additive on board. (Fire retardant and thickeners are added to stop the water boiling away or running into the soil when dropped in lines around the fire. Modern retardants act as fertilisers to encourage and assist re-growth too.) They use the natural water resources close to the target to refill their water tanks as many times as needed by skimming the lake surface with underbelly scoops, and gather up almost 500 litres (132 gallons) of water per second. Over the target, a small command aircraft circles to guide the bomber in.

On approach, the water bomber will descend past the fire and fly downwind, before making a 180-degree turn around the fire, and dropping to a height of under 35 metres (115 feet) to make its attack run. Dropping its load in one of several ways – all at once, a long stream or as a fine mist – the bomber normally does not hit the fire itself, but lays the liquid in front or alongside the flames, to stop them from spreading. Once the fire is contained, direct attacks to put it out may be used if necessary. Guidelines vary, with 0.2 litres (0.4 pints) per square metre being the recommended minimum, but it can take as much as 4 litres (8.5 pints) of water and additives per square metre to treat a large fire, so the payload carried by the Canadair Scooper, for instance, can wet an area as large as a town or as small as a football field depending on the concentration of liquid that is required.

Oxidisation and water tanks on board a CL-215

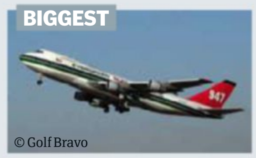
© Cambridge Bay Weather

The Canadair CL-215 can take off from both water and runway

Head to Head
FIREFIGHTER PLANES

1. Canadair CL-215
Carrying up to 4,900 litres (1,300 gallons) the Scooper is no lightweight, and is classed as a medium-sized air tanker.

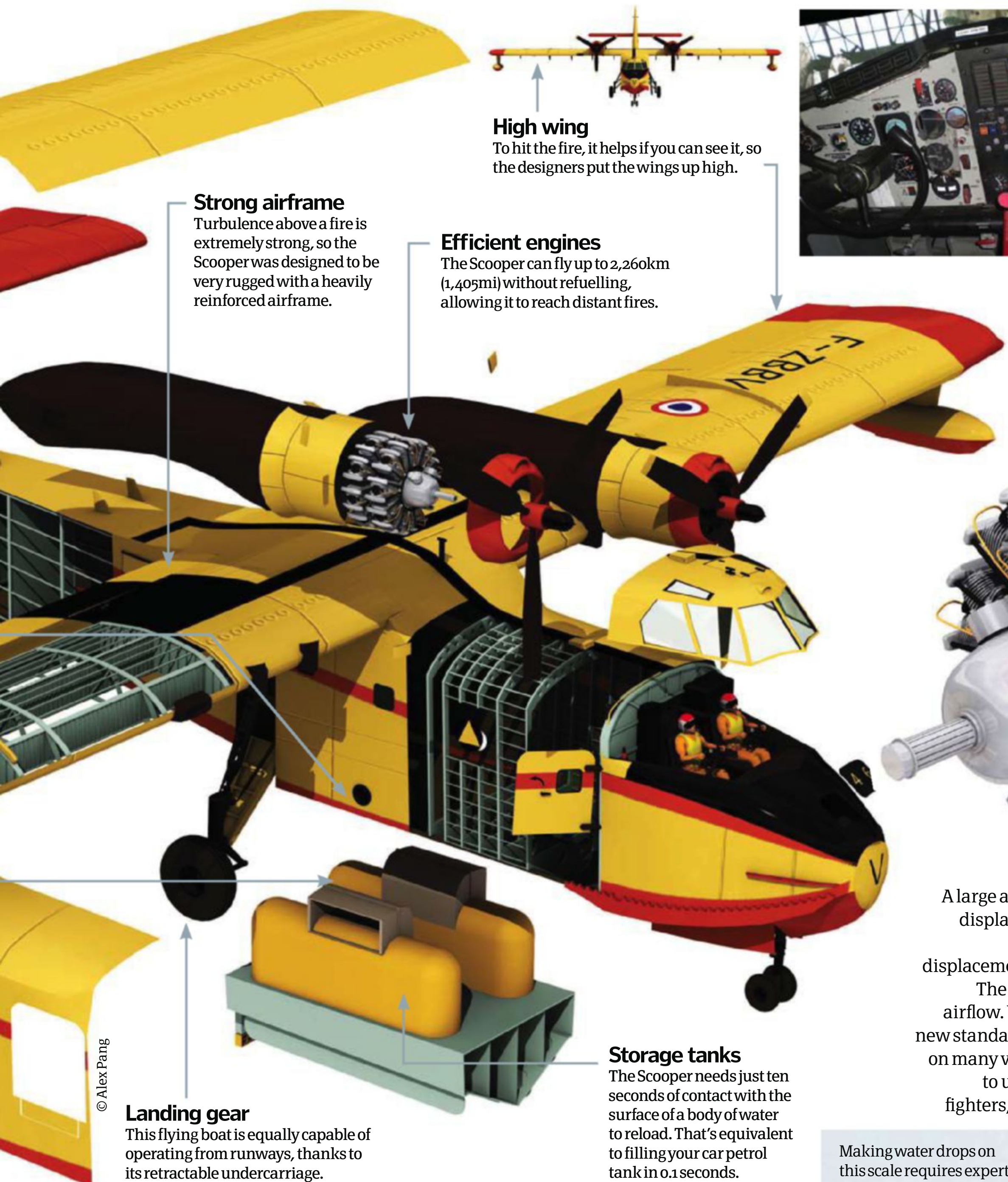
2. Lockheed C-130 Hercules
Retrofitting former military aircraft to hold 11,000 litres (3,000 gallons) of liquid makes this an extremely capable firefighter.



© Golf Bravo

3. Evergreen 747 Supertanker
Nothing comes close to the scarcely imaginable 78,000 litres (20,500 gallons) that are fired from high-pressure jets under this flying behemoth.

DID YOU KNOW? Iron ferrite (better known as rust) is used to colour the liquid and identify where drops have been made



High wing
To hit the fire, it helps if you can see it, so the designers put the wings up high.

Strong airframe
Turbulence above a fire is extremely strong, so the Scooper was designed to be very rugged with a heavily reinforced airframe.

Efficient engines
The Scooper can fly up to 2,260km (1,405mi) without refuelling, allowing it to reach distant fires.

Landing gear
This flying boat is equally capable of operating from runways, thanks to its retractable undercarriage.

Storage tanks
The Scooper needs just ten seconds of contact with the surface of a body of water to reload. That's equivalent to filling your car petrol tank in 0.1 seconds.

© Alex Pang

© Cambridge Bay Weather

R-2800-54 Double Wasp

Take a closer look at the engine of the Pratt and Whitney R-2800

A large aircraft needs large motors, and with an overall displacement of 46,000cc each, the R-2800s are huge. These 1,567kW engines have roughly the same displacement and power output as 13 average family cars. The engine uses fins to transfer heat to the passing airflow. When the Double Wasp was first released it set new standards in power output, using superchargers and, on many variants, water injection. Other notable aircraft to use this type of engine include the World War II fighters, F4U Corsair, F6F Hellcat and P-47 Thunderbolt.

© Alan Radecki

Risky business

Firefighting is a dangerous business anyway, but when you take your equipment into the sky and fight the fire from above, a whole new set of challenges arise. To carry enough water or chemicals to be effective, the aircraft must not only lift the weight but it must also remain highly manoeuvrable with many tons of liquid on board. The aircraft will need to fly very low, under 35 metres (115 feet), through difficult, rugged terrain. Fire causes a lot of air turbulence; gaining then losing lift as you pass through the layers of rising and falling air puts huge structural stress on the aircraft. Making a drop puts the aircraft out of balance as the lift-to-weight ratio suddenly changes and a tank going from full to empty can make the aircraft dangerously nose- or tail-heavy. Though baffles (dividing sections inside the tanks) and 'anti-slosh' tools (such as foam or honeycombed structures) are used, it is always potentially dangerous to have large amounts of liquid moving around.

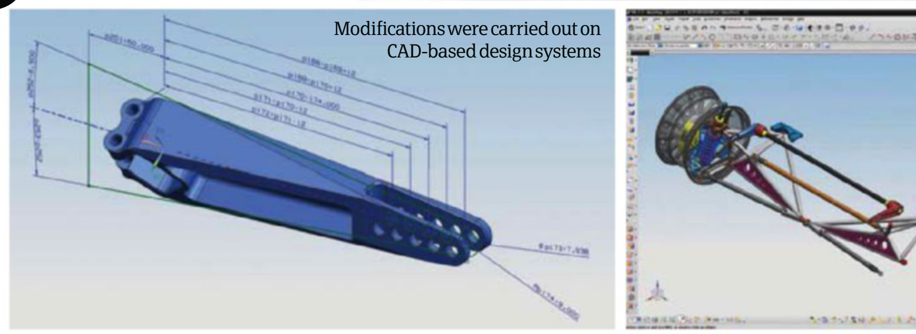
Making water drops on this scale requires expert piloting skills

© Vlsergey

How to build a touring car

The Cruze's design team ensured it had a wide track to improve stability when cornering

Chevrolet knows a thing or two about building a world-class touring car, having won both 2011's FIA WTCC's Manufacturers' and Drivers' Championships. We take a closer look at its trophy-winning design



Modifications were carried out on CAD-based design systems

A standard four-door saloon capable of outputting a modest 113 brake horsepower and reaching 97 kilometres (60 miles) per hour in a rather stately 11.8 seconds, or a lowered and turbo-charged racing monster capable of outputting 310 brake horsepower and annihilating 0-60 in under four seconds? For the FIA World Touring Car Championship (WTCC) it is definitely the latter for Chevrolet's race-specified Cruze – and what a car it is, winning the manufacturer both the 2010 and 2011 titles back-to-back.

Key to the Cruze's success from a mechanical standpoint has been its ground-up redesign by a dedicated in-house team of engineers, in which substantial modifications have been made to the standard road car to ensure blistering speed and superb handling performance. The vehicle is lighter, stiffer and more aerodynamic than ever before and these enhancements, partnered with a host of bespoke components and clean-sheet engine redesign, have paid dividends.

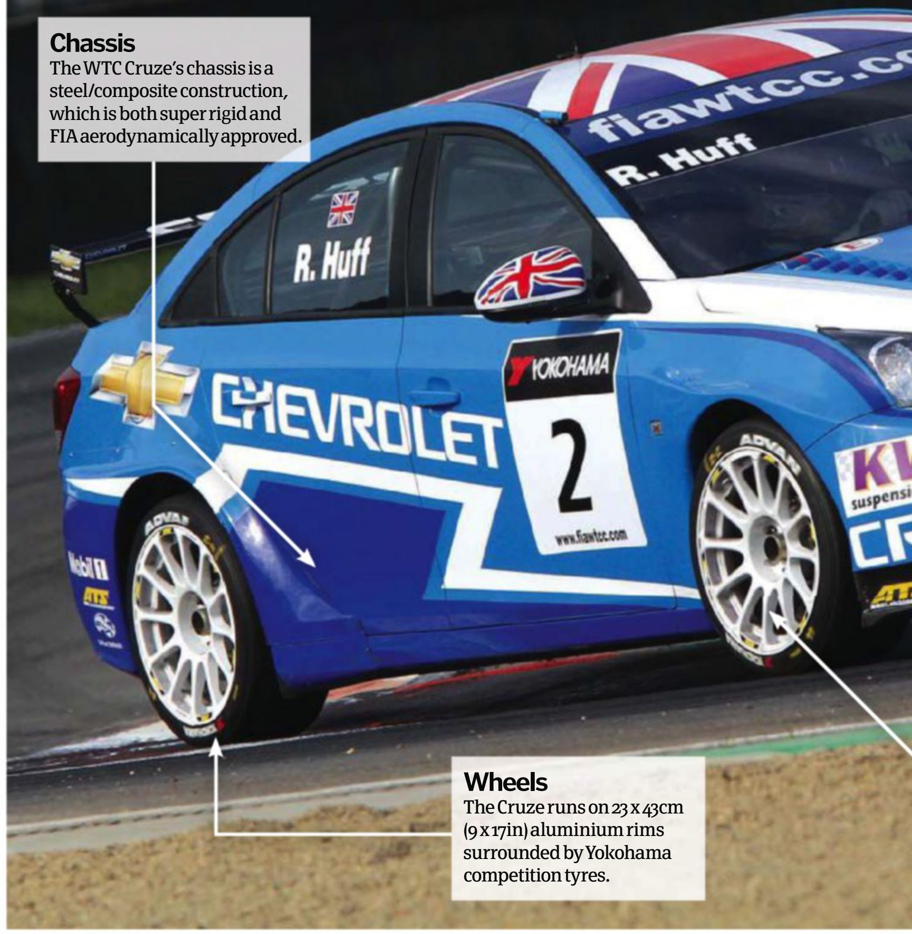
The WTC Cruze's engine is a 1.6-litre (0.5-gallon), turbo-charged, four-cylinder beast, designed specifically to seamlessly mesh with the vehicle's transmission and chassis. Further, thanks to all elements of its design being handled by the British-based RML Group, it has been specially tailored to improve engine mileage over the whole WTCC season. As well as the engine, the WTC Cruze has also been equipped with a brand-new independent rear-suspension system, strength-enhanced wheel bearing packs, front and back machined aluminium callipers with vented steel discs, a curved roll-cage and a six-speed sequential shift transmission. All of these elements are custom built to ensure optimum race performance.

While working from the Cruze's donor road-car shell, the chassis of the vehicle has also seen substantial modification. The shell has been reinforced for enhanced stiffness, its track has been elongated, bootline raised, roof flow attachment augmented and driver windscreen altered for maximum visibility. These changes partnered with incremental adjustments to the ride height, damper settings and suspension springs to deliver a more aggressive and aerodynamically fluid profile.

Of course, not all credit can be taken by the car itself, with Chevrolet also delivering one of the most high-tech race outfits in the tournament. The large team of technicians and engineers are continuously evaluating each vehicle's performance pre-, during and post-race, frequently fine-tuning settings to suit. Indeed, judging by the impressive stats, it's difficult to see how any other manufacturer will come close to matching them in 2012.

Cruze touring car fundamentals

We break down the major components of this souped-up road car



Chassis
The WTC Cruze's chassis is a steel/composite construction, which is both super rigid and FIA aerodynamically approved.

Wheels
The Cruze runs on 23 x 43cm (9 x 17in) aluminium rims surrounded by Yokohama competition tyres.

5 TOP FACTS
WORLD TOURING CAR CHAMPIONSHIP

First
1 The first World Touring Car Championship was held in 1987, with races over numerous countries. The Drivers' Championship was won by Roberto Ravaglia in a BMW M3.

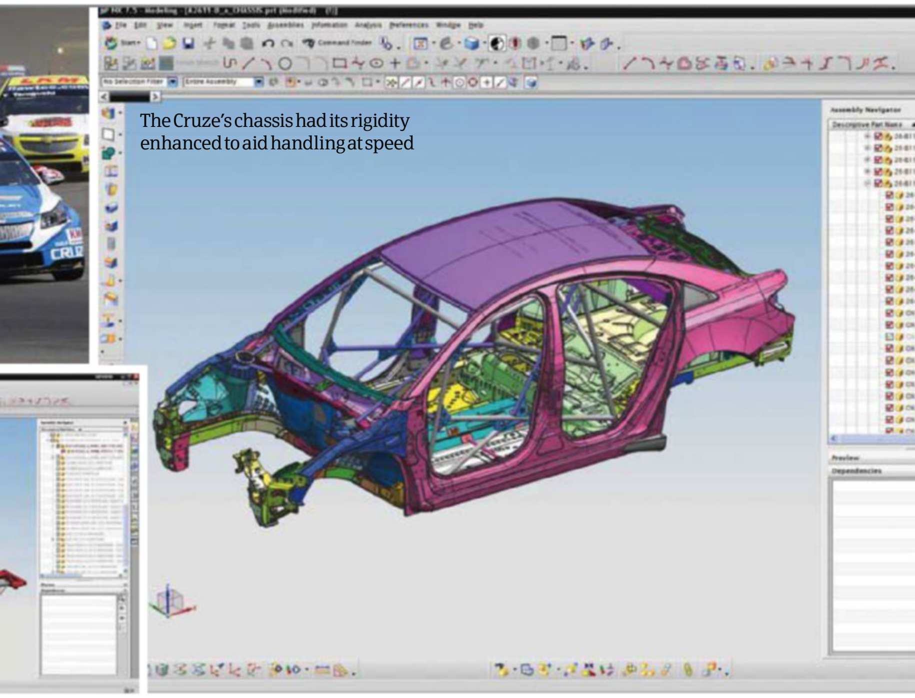
Scoring
2 The WTCC's scoring system delivers points in a descending order from first to tenth. Points start at 25 for first place and drop incrementally to one for tenth position.

Cruzing
3 Since entering the World Touring Car Championship in 2009, the Chevrolet Cruze has racked up many podium places, winning the company both the 2010 and 2011 championships.

Winner
4 This year's WTCC was won by Yvan Muller for Chevrolet. He beat fellow Chevrolet driver Rob Huff by just three points, with the final scores coming in at 433 points versus 430.

Dominance
5 As well as claiming victory in the Manufacturers' Championship in 2011, drivers from Chevrolet also accounted for the top three positions in the Drivers' Championship.

DID YOU KNOW? *BMW, SEAT, Volvo and Chevrolet all compete in the World Touring Car Championship*


The Cruze's chassis had its rigidity enhanced to aid handling at speed

Engine
The Cruze WTC 2011 is equipped with a 1.6-litre (0.5-gallon), direct injection, four-cylinder engine. It produces 300bhp.

Suspension
The Cruze's front suspension is handled by a MacPherson strut, while the rear is a custom pseudo trailing twist axle.

Brakes
Both front and back brakes include machined aluminium callipers, vented steel discs and are air-cooled.

Meet team Chevrolet

Chevrolet's team took the top three positions in 2011's WTCC tournament

Yvan Muller

Muller won this year's tournament by just three points, with a pitched battle between himself and fellow team-mate Robert Huff, only decided in the last race of the season. Muller was born in Altkirch, France.

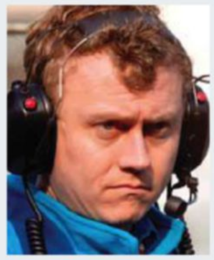
Robert Huff

Huff had a fantastic season in 2011 coming second in the Drivers' Championship by just three points, a personal record for him. He has previously come third twice. Huff was born in Cambridge, England.

Alain Menu

Menu broke into the top three drivers for the first time in 2011 and ensured a clean sweep for Chevrolet in the Drivers' Championship. Menu was born in Geneva, Switzerland.

INTERVIEW



Mark Way

We speak to the chief designer of the WTC Cruze about the challenges of building a race-specified touring car

How It Works: What is your role at Chevrolet and what is your background experience?

Mark Way: I am head of design on the Chevrolet WTC programme. I've been here since the project started in 2004 and in that time we have seen the car develop and become competitive. We have a small design team here of about three people on the chassis side and we also do the engine in house as well.

The current car has a 1.6-litre [0.5-gallon] engine in it, which has had a clean-sheet design, so we have done all the castings ourselves. The combination of that engine and what we do on the chassis means that we are pretty much doing everything aside from receiving the donor body shell.

HIW: Can you tell us a little about the WTCC and why Chevrolet is taking part?

MW: The programme timed with Chevrolet being expanded to a worldwide brand so Chevrolet saw this as an opportunity for promotion. Traditionally Chevrolet has been confined to North America, but it is now increasingly popular [globally] and we've got a lot of big markets – Europe being one of the biggest, but also China. So it was a way of promoting the brand and getting into these new markets.

HIW: Why was the Cruze chosen as the base for the touring car? Does this model have certain advantageous characteristics?

MW: The programme started with us running a Chevrolet Lacetti and the Lacetti was born out of General Motors [GM]. So when the Lacetti was coming towards the end of its life we needed to decide which car we were going to race from the Chevrolet range; the Cruze fitted the bill. It was one of the first full designs undertaken by GM.

HIW: Tell us about the process of transforming the Cruze road car into its racing equivalent.

MW: There is a certain amount we have to use from the road car, the body shell being the most obvious, but also the front sub-frame is carried over and the front suspension geometry too. That can be modified in certain [ways], however, and we then replace most of the road car components with our own bespoke variants.

The fundamental road car geometry remains, though, within the constraints laid down. The rear suspension has been completely replaced, although the fundamental operating principle has been carried over. Bodywork-wise it is very recognisable as the Cruze, however we have made it much wider and the front bumper has had a lot of work done to it to package radiators and intercoolers.

HIW: Could you give an example of how these modifications aid the vehicle's performance?

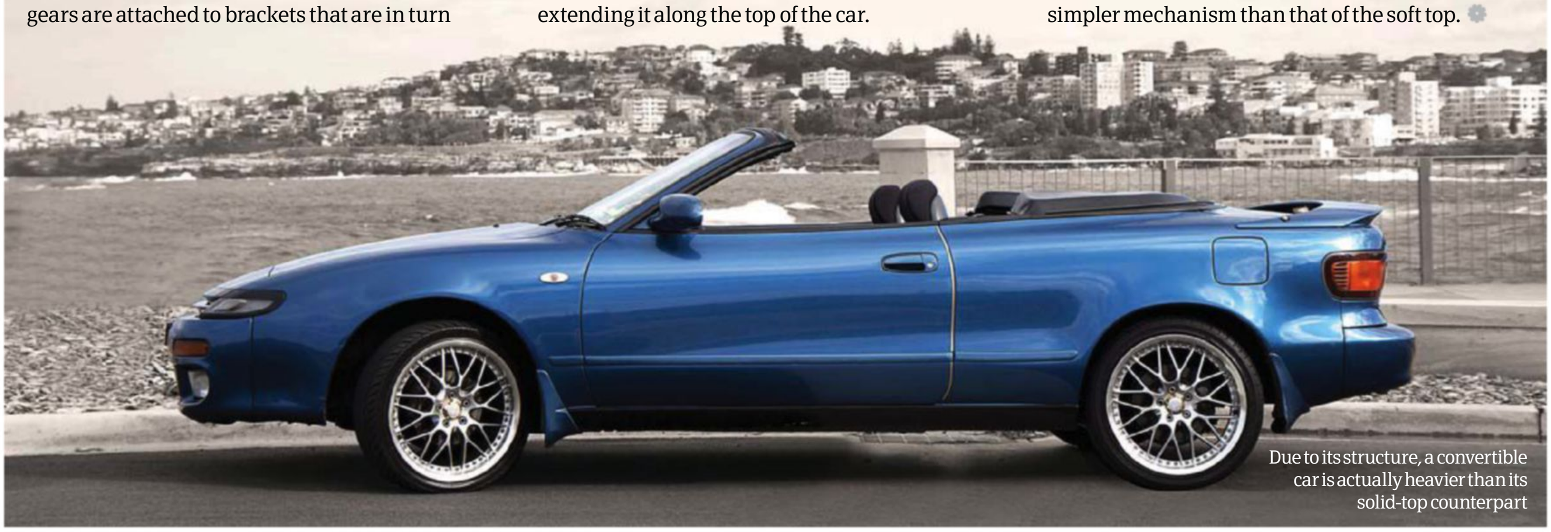
MW: Within the regulations you can widen the car by a certain percentage. [Generally this] makes the touring car look more aggressive. Purely from a vehicle dynamics point of view though, going wider helps improve corner stability and also limits the amount of weight transfer. Basically, as a general rule, the wider a car is the faster it will be.

Convertible cars

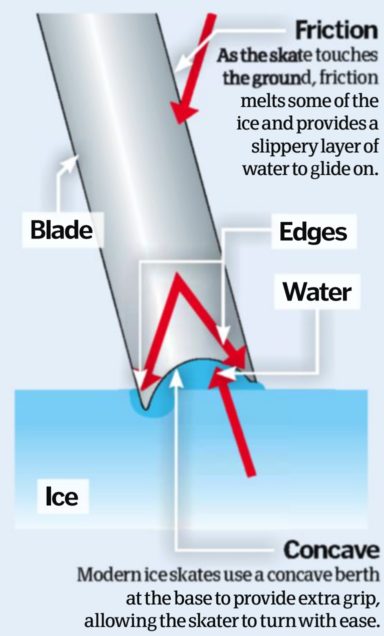
How do these vehicles retract their roofs?

Most convertible roofs in use today are known as soft tops. These are power operated but must be manually latched and unlatched from the car. Usually made of vinyl or canvas, they are powered by mechanical gears on either side of the car. The gears are attached to brackets that are in turn connected to the main part of the roof. As the gears rotate the brackets move the roof forwards or backwards, depending on if it is closing or opening. Along the rim of the roof, scissor-like metal links provide the rigidity and flexibility of the roof, folding the soft structure down or extending it along the top of the car.

The other type of convertible roof is the hard top. It is made of a rigid material such as steel or aluminium, and thus does not need to be supported by brackets along the side of the car. A combination of motors and sensors control the automatic extension and retraction of this roof, a simpler mechanism than that of the soft top.



Due to its structure, a convertible car is actually heavier than its solid-top counterpart



How ice skates work

The science behind gliding across ice

Ice skates have reportedly been used since 3000 BC, although their design has changed quite considerably from a pointed base to a concave hollow; the latter modern type is what is demonstrated in the diagram to the right.

Ice skates make use of the fact that ice can become slippery when water is introduced, enabling skaters to easily glide across large rinks. Although ice is solid, at -20 degrees Centigrade (-4 degrees Fahrenheit) it melts slightly, so that a thin layer of water forms on its surface. This is the reason why ice can be so slippery; the more water present, the more slippery it gets. As an ice skate travels across its surface, the friction caused by its motion will lead to more melted ice. This allows the ultra-narrow and smooth skate blade to glide over as if it were travelling on a thin layer of liquid.

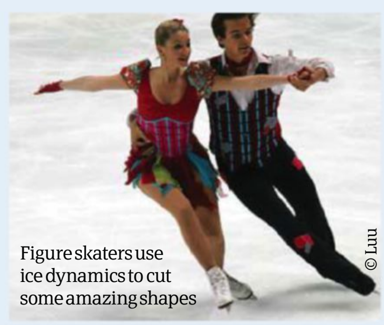


Figure skaters use ice dynamics to cut some amazing shapes

© Luu

5 TOP FACTS CABLE CARS

Sans cable
1 Despite still being called cable cars, the majority of modern-day cable cars are not powered by cables at all. Most lines were converted to electric systems in the early 20th century.

Hallidie
2 The cable car was invented by Andrew Smith Hallidie who installed the first system in San Francisco in 1873. The line ran on Sacramento and Clay Streets within the city.

Decks
3 By 1920 cable cars had spread to London, England, where electric varieties operated through the city centre. These cars were usually double-deck rather than single-deck.

Abandoned
4 Unfortunately, due to the rise of automobiles between the Thirties and Fifties, cable cars began to be replaced by buses and cars. By 1955 there were no cable cars left in London.

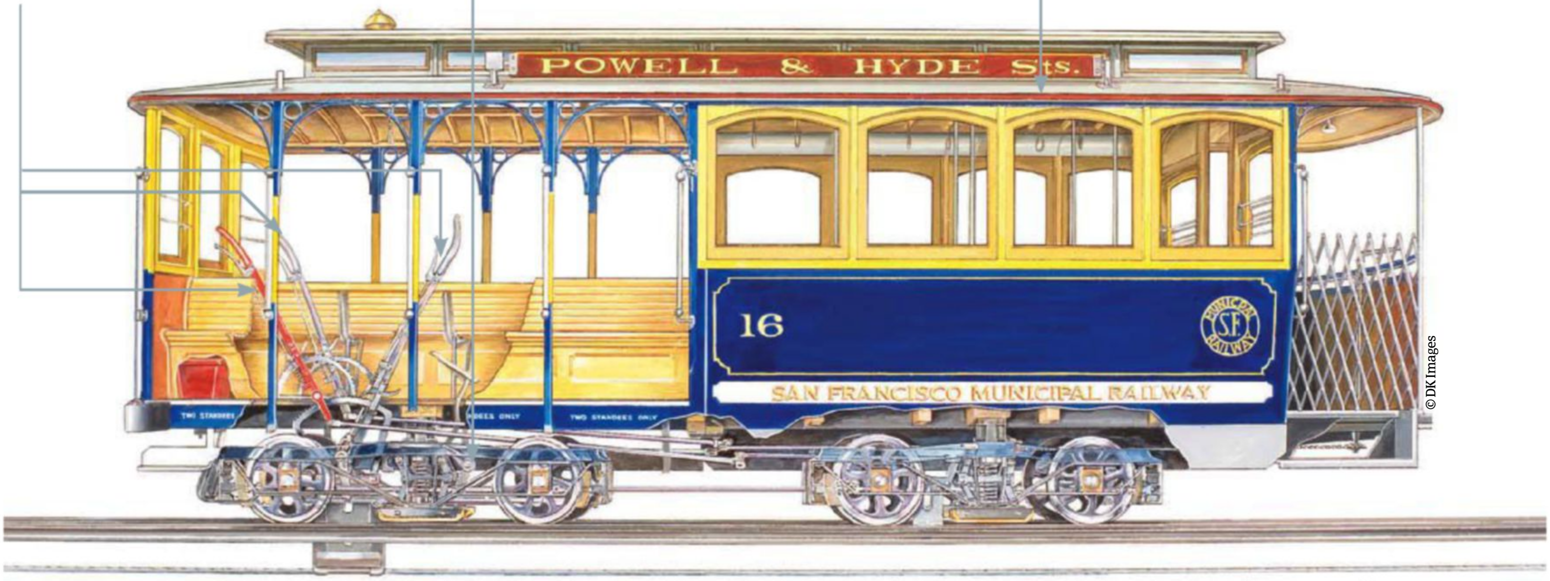
Renaissance
5 Due to increased fuel prices and population growth, cable car systems have recently made a comeback, with new systems installed in major cities such as Houston and Washington DC.

DID YOU KNOW? *The first cable car in San Francisco was introduced in 1873*

Control levers
There are multiple levers that the grip person must operate on each cable car, including the central grip lever – responsible for attaching the carriage to the drive cable – as well as three separate brake levers.

Brakes
Each car has three brake types. Wheel brakes are steel pads that press against each wheel, track brakes are wooden blocks that press against the rails and the emergency brake is a 46cm (18in) steel wedge that slots between the tracks.

Carriage
There are two main types of San Francisco cable car: single and double ended. These range in size from 8.6-9.2m (28.2-30.2ft) in length and weigh over 7,000kg (15,432lbs). The carriages are wooden and can carry up to 68 passengers.



San Francisco cable cars

How are these novel trams powered and operated?

The San Francisco cable car system consists of 40 single and double-ended, wooden carriages and four main drive cables that cover two major routes in the Californian city. All the carriages are moved by their attachment to one of the four underground cables, which continuously move at a speed of 15.2 kilometres per hour (9.5 miles per hour). The drive cables themselves are powered by four 510-horsepower DC electric motors located at the network's central power house, which is between the city's central Washington and Jackson Streets.

The carriages grip the moving cable via a complex system of in-car levers and mechanisms, which are operated by an onboard grip person. There are commonly four levers within each car – a central grip/ratchet lever as well as three separate brake levers. The grip lever operates on a linear plane, either rising or lowering the carriage's grip system from beneath the underground cable. To attach the carriage to the cable, firstly the operator must lower the centre plate beneath the floor of the car. Attached to the centre plate are two hinges, which when the operator engages the ratchet lever, are forced by twin rollers to tighten on top of two semi-cylindrical dies. These dies close on to the cable like a vice, instigating carriage movement. The grip intensity on the drive cable determines the speed of the carriage, something closely controlled by the operator.

As forward momentum is granted by a revolving cable, when a carriage needs to stop, firstly the grip on the drive cable needs to be released. Often, experienced drivers do this in advance of a stop, using the car's weight to slow down without assistance. However, due to San Francisco's terrain – which includes numerous steep hills, high traffic flow and dense population, more often than not carriages need to actively engage their braking systems. The first of these are wheel brakes, which are steel brake pads fitted to each of the carriage's wheels. When the operator applies the brake lever, the pads come into contact with the wheels, causing friction and reducing speed. The second brake lever instigates a similar process but this time with the rails themselves, while the third brake – designed for emergencies – drives a 46-centimetre (18-inch) steel wedge into the ground. This final lever is only used to prevent a major accident.

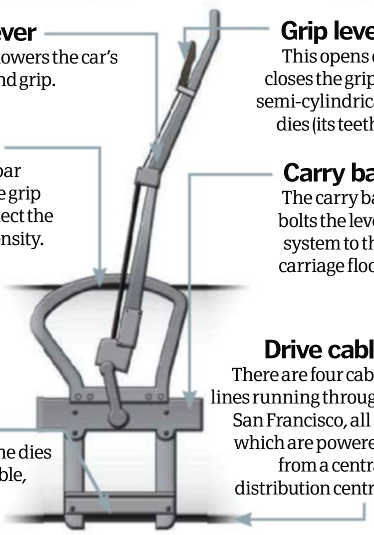
Finally, due to the one-way linear motion of the drive cables, carriages cannot simply reverse direction like a regular train or other autonomously powered shuttle. To switch direction, the carriages need to be 'turned' at one of four turning circles located throughout the city. These work by positioning the carriage onto a rotating platform, disengaging the carriage's cable grip, moving the carriage in line with another cable, and then re-engaging the grip to continue the journey.

Ratchet lever
This raises or lowers the car's centre plate and grip.

Grip lever
This opens or closes the grip's semi-cylindrical dies (its teeth).

Quadrant
A measuring bar that allows the grip operator to select the cable grip intensity.

Carry bar
The carry bar bolts the lever system to the carriage floor.



Drive cable
There are four cable lines running through San Francisco, all of which are powered from a central distribution centre.

Rollers
Rollers force the dies against the cable, akin to a vice.

The cable system in San Francisco is perfectly adapted to the city's steep hills

Supertankers explained

These floating oil fields carry the energy needs of a nation in their ample bellies

The world thirsts for oil. Every day our cars, trucks, furnaces and planes drink up 85 million barrels of crude oil in the form of gasoline, diesel fuel, kerosene, jet fuel and dozens of useful petroleum by-products including that Vaseline you rubbed on your lips this morning. Try to imagine what 85 million steel drums of oil look like – and that's one single day. While Europe and North America remain the largest consumers of oil, our addiction to energy is now a global phenomenon. There is only one way to transport millions of barrels of black gold from the rich oil fields of Russia and Saudi Arabia to the US, Japan and beyond: within the bellies of the largest ships in the world.

Supertankers are high-seas oil tankers that have been supersized to satisfy our colossal modern energy appetite. The biggest of these floating behemoths can carry the equivalent of over 3 million barrels of crude oil in its dozens of below-deck storage tanks; that's more oil than England and Spain consume every day.

Over the course of a year, hundreds of supertankers criss-cross the world's oceans and arctic seas transporting over 2 billion barrels of oil with tremendous efficiency. Second only to oil pipelines, these massive ships cost the equivalent of two US cents per gallon to operate.

That's not to say they are cheap, however. A brand-new ultra large crude carrier (ULCC) will cost £80-100 million. They are constructed in the goliath shipyards of South Korea and China, which combine to handle over 80 per cent of the world's shipbuilding. Supertankers are welded together from huge prefab structures called megablocks. The vessels are designed with two chief goals in mind: to maximise the amount of oil the ship can carry; and to get it to its destination safely.

The first way to maximise carrying capacity is to get bigger. The largest supertanker ever to sail the oceans was the Seawise Giant, weighing in at 564,763 deadweight tons (DWT). If you stood the Seawise Giant on its stern, it would be taller than nearly every skyscraper in the world. Today's supertankers hover around the more reasonable, but still gigantic, 300,000 DWT mark.

In addition to sheer size, supertankers maximise their carrying capacity by filling nearly the entire hold with storage tanks. Modern tankers don't carry actual barrels. Oil is pumped from the shore through a system of on-deck pipelines into dozens of below-deck storage tanks. By using many smaller storage tanks, shipbuilders minimise the effects of sloshing (see 'Slosh dynamics' box). While a smaller tank filled to capacity won't slosh and shift its weight on the

DID YOU KNOW?

The biggest supertanker ever built

The Seawise Giant carried a maximum weight of 564,763 DWT and contained 46 storage tanks when it was constructed in 1979. Stood on its head, the Seawise Giant is taller than the Petronas Towers in Malaysia, which stand at 452 metres (1,482 feet) tall.

DID YOU KNOW? A supertanker transporting liquid natural gas has more energy potential than six Hiroshima-scale bombs


A bird's eye view of the prow of an oil tanker

Slosh dynamics

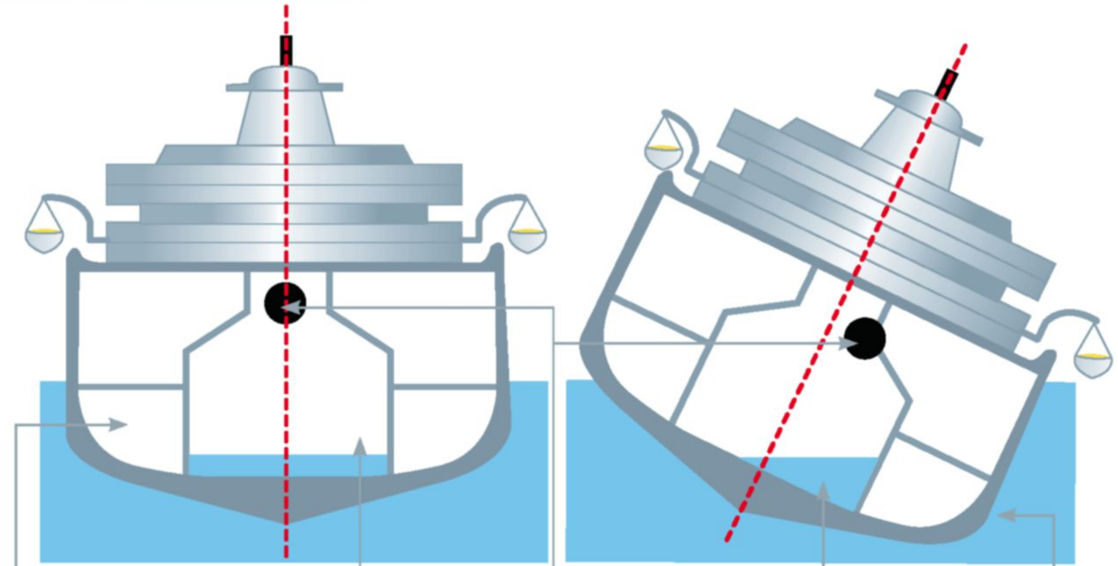
Despite their incredible size and weight, supertankers are surprisingly vulnerable to capsizing. That's because they are filled with liquid cargo, which sloshes about with great force, dangerously altering the ship's centre of gravity. The worst scenario is a large storage tank only partially filled. The liquid in this 'slack tank' will slosh and shift with sudden manoeuvres of the ship or outside forces like strong waves or wind gusts. Since the liquid sloshes in the same direction as the roll, it exaggerates the pitch of the vessel, creating something called the free surface effect. As the vessel tries to right itself to centre, the liquid sloshes even more violently in the opposite direction, initiating a positive feedback loop that can eventually lead to disaster. To mitigate the dangers of the free surface effect, supertankers use several smaller storage tanks and either fill them to the top (a 'pressed up' tank) or leave them empty.

high seas, a large, half-empty tank could slosh with enough force to capsize even a supertanker. Once the ship reaches its destination, a powerful on-board pump sucks the oil from the tanks and transports it to an on-shore pipeline, storage facility or to a smaller tanker.

Safety is a major consideration on a supertanker. First and foremost, you must remember you are transporting massive quantities of a highly flammable liquid. (Every oil tanker features a large stencilled 'No smoking' sign over the crew quarters!) It turns out that the greatest danger is not the oil itself, but the vapours that can become trapped in the partially filled tanks. That's why modern oil tankers employ an automated inert gas system that fills unused portions of a storage tank with a cocktail of gases that render the vapour inflammable.

Oil leaks and spills are another big concern, both for economic and environmental reasons. In the wake of the infamous Exxon Valdez oil spill in 1989, all modern oil tankers are required to have double-hull construction. The inner hull containing the storage tanks is protected by an outer hull; these are divided by a three-metre (ten-foot) gap. When the tanker is full, the space between the hulls is left empty, forming an effective crumple zone. When the tanker unburdens its load of oil, the space is filled with water to act as ballast.

Temperature is another serious concern for supertankers. Crude oil and other fuel products can get thick and sticky if they are allowed to become too cold, making them nearly impossible to unload. When supertankers cross through near-frozen arctic waters, they maintain the desired oil temperature by pumping hot steam through coils underneath each storage tank.



Rocking the boat
The free surface effect can be mitigated by using smaller, off-centre tanks and filling them to capacity.

Slack tank
The free surface effect is exaggerated in a partially filled tank, where liquid moves freely over a large area.

Centre of gravity
If enough liquid sloshes with enough force, it can alter the vessel's centre of gravity and leave the ship unable to right itself.

Slosh
If the ship's manoeuvring or an outside force tips it starboard, the liquid will slosh in the same direction, deepening the roll.

Displacement
Normally, a slight roll is counteracted by the upward pressure of the water displaced. Sloshing liquid acts against that correcting force.


Crude oil is a mixture of compounds known as hydrocarbons

What is crude oil?

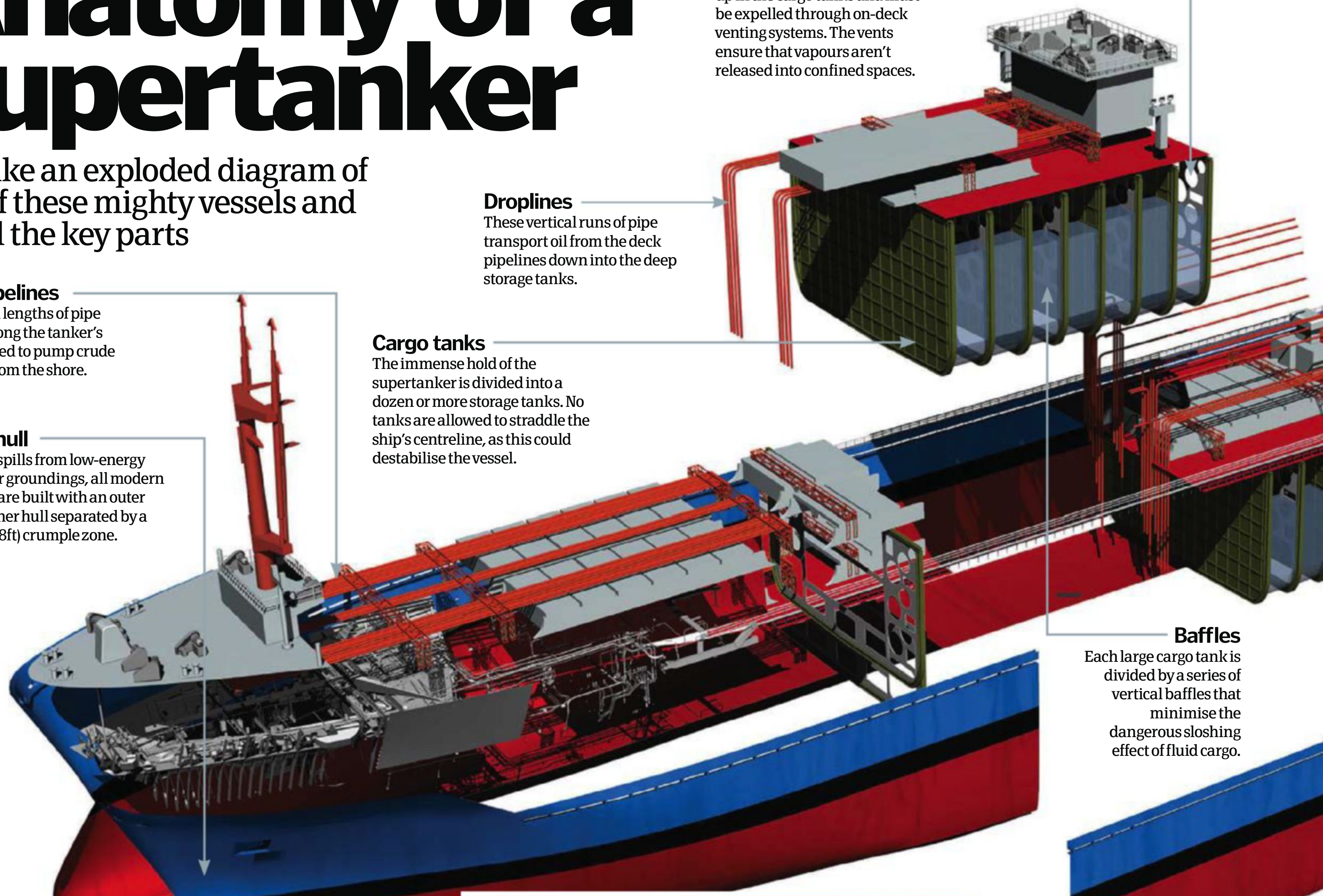
Crude oil is the raw, unprocessed petroleum that is pumped out of the ground through oil drilling. The composition of crude oil varies greatly with the location of the underground oil deposit. The main ingredient of crude oil is carbon, which makes up 83-87 per cent of the mix. There are also natural gases bubbling through the thick liquid such as methane, butane, ethane and propane, composed of hydrogen, nitrogen, oxygen and sulphur in varying quantities. The black/brown crude is shipped to oil refineries, where it is purified and separated into commodities like gasoline, diesel fuel, kerosene and liquid natural gas.

Deadweight tonnage

Following the principle of Archimedes' "Eureka!" moment, if you lower a floating vessel into water, a force called buoyancy pushes upwards on the hull with a force equal to the weight of the water it displaces. Buoyancy only works on objects that are less dense than water. It is the huge volume of air in the hull that allows supertankers to float. Because displacement equals weight, we can figure out the total weight of a ship – known as deadweight tonnage – by measuring the height of the waterline against markers painted on the ship's hull.

Anatomy of a supertanker

We take an exploded diagram of one of these mighty vessels and detail the key parts



Deck pipelines
These fixed lengths of pipe running along the tanker's deck are used to pump crude oil to and from the shore.

Double hull
To prevent spills from low-energy collisions or groundings, all modern oil tankers are built with an outer hull and inner hull separated by a 2-3m (6.6-9.8ft) crumple zone.

Cargo tanks
The immense hold of the supertanker is divided into a dozen or more storage tanks. No tanks are allowed to straddle the ship's centreline, as this could destabilise the vessel.

Droplines
These vertical runs of pipe transport oil from the deck pipelines down into the deep storage tanks.

Vents
Flammable vapours can build up in the cargo tanks and must be expelled through on-deck venting systems. The vents ensure that vapours aren't released into confined spaces.

Baffles
Each large cargo tank is divided by a series of vertical baffles that minimise the dangerous sloshing effect of fluid cargo.


One of the massive storage tanks that can be found on a supertanker

© Science Photo Library

Oil tanker timeline

1860s
Wind-powered tankers
A large sailing vessel like the Elizabeth Watts could hold several hundred tons of crude oil, but ocean travel was slow.

1873
First steam tanker
The SS Vaderland is believed to be the first oil tanker powered by a steam engine. They had featured on other types of ship since 1843.

1886
Prototype modern tanker
The British-built Gluckauf was one of the first to have many large, permanent storage tanks in its hold, instead of stacking in barrels.

Head to Head
GIANTS OF THE SEA

BIGGEST CRUISE SHIP

1. Allure of the Seas and Oasis of the Seas
These Royal Caribbean cruise liners are 16 decks high and carry over 6,000 passengers in 2,700 rooms.

BIGGEST WARSHIP

2. Nimitz-class aircraft carriers
These nuclear-powered war machines are 333m (1,092ft) long and can travel at a top speed of 55.5km/h (30 knots).

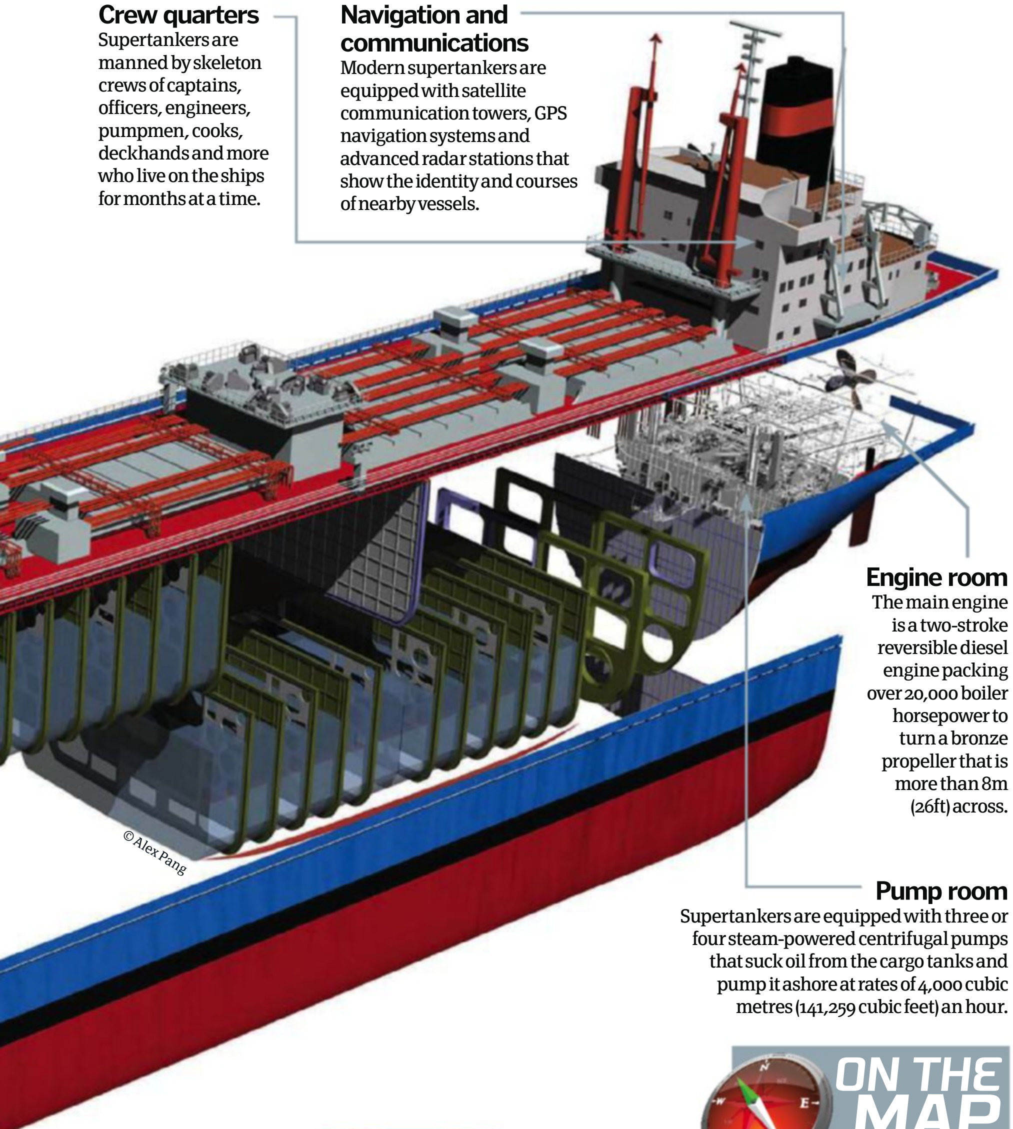
BIGGEST WOODEN SHIP

3. Wyoming
Measuring 140m (450ft), this turn-of-the-century schooner had six masts and could reach a top speed of 30km/h (16 knots). It sunk in 1924, claiming all 14 hands on board.

DID YOU KNOW? Supertankers aren't built for agility; it can take 15 minutes for one to shift from full forward to full reverse

Crew quarters
Supertankers are manned by skeleton crews of captains, officers, engineers, pumpmen, cooks, deckhands and more who live on the ships for months at a time.

Navigation and communications
Modern supertankers are equipped with satellite communication towers, GPS navigation systems and advanced radar stations that show the identity and courses of nearby vessels.



Engine room
The main engine is a two-stroke reversible diesel engine packing over 20,000 boiler horsepower to turn a bronze propeller that is more than 8m (26ft) across.

Pump room
Supertankers are equipped with three or four steam-powered centrifugal pumps that suck oil from the cargo tanks and pump it ashore at rates of 4,000 cubic metres (141,259 cubic feet) an hour.

ON THE MAP

Top oil producers*
1 **Country:** Russia
Barrels per day: 9.93m
2 **Country:** Saudi Arabia
Barrels per day: 9.76m
3 **Country:** United States
Barrels per day: 9.14m
4 **Country:** Iran
Barrels per day: 4.17m
5 **Country:** China
Barrels per day: 4.00m
*Source: US Energy Information Administration

1903
Internal-combustion tankers
Alfred Nobel's brothers, Ludvig and Robert, were oil tanker innovators. The Vandal was their first diesel-electric ship, powered by three 120hp diesel motors.

1915
Wartime refuelling
The USS Maumee was the first large oil tanker used to refuel destroyers on their long Atlantic voyage from America to the UK.

1958
First supertanker
The Japanese-built SS Universe Apollo was the first oil tanker to exceed 100,000 deadweight tons.

Oil tanker classification

Oil tankers come in all sizes. Here we explain the differences and what it takes to qualify as a supertanker

Medium-range tanker
<44,999 DWT (deadweight tons)

According to a system developed by Shell Oil called the average freight weight assessment, oil tankers are classified by the maximum amount of deadweight tons (DWT) they can carry. Medium-range tankers handle up to 44,999 DWT and include the Seawaymax class of tankers, the largest vessels that can pass from the interior Great Lakes of the US-Canadian border to the Atlantic Ocean via the St Lawrence Seaway.

Long-range tanker 1 (LR1)
45,000-79,000 DWT

Tankers classified as LR1 can carry between 45,000 and 79,000 DWT, which may be small on a supertanker scale, however LR1 tankers do have their advantages. For example, no tanker larger than an LR1 can squeeze through the narrow locks of the Panama Canal, which can shave many miles off a journey.

Long-range tanker 2 (LR2)
<160,000 DWT

Some LR2 tankers are twice as large as the heaviest LR1s, reaching a maximum weight of 160,000 DWT. Smaller tankers in the LR2 class roam the waters of shallower sea basins like the North Sea, Black Sea and the Caribbean. The largest LR2s still float shallow enough to pass through the Suez Canal, thus avoiding the long journey around the southern tip of Africa.

Very large crude carrier (VLCC)
<319,999 DWT

From the VLCC class up is officially supertanker territory. VLCCs weigh in at a maximum 319,999 DWT. VLCCs are also known as Malaccamax craft, because they are the largest tankers that can fit through the Strait of Malacca – a 25-metre (82-foot)-deep pass between Malaysia and Sumatra – the most direct sea route from the oil-rich Middle East to oil-hungry China.

Ultra large crude carrier (ULCC)
<500,000 DWT

These gargantuan vessels – more like small, floating nation-states – are the monsters of the supertanker world, with a maximum carrying capacity of 500,000 DWT. The typical ULCC can transport over 3 million barrels of oil, more than the combined daily energy usage of England and Spain. Most ULCCs are too big to fit through canals, so they must take the scenic route around the southern tips of Africa and South America.

Snow tyres

When the weather turns bad, a winter tyre comes into its own, thanks to physics and clever design

A cold-weather tyre is one that is optimised for winter conditions. When temperatures drop below seven degrees Celsius (45 degrees Fahrenheit), winter tyres are at their most effective – just as the rubber of normal tyres begins to harden and become less efficient. Winter tyres are becoming much more popular in the UK and are a legal requirement in some European countries.

Winter tyres have smaller tread blocks with far more thin slits, or sipes, on the surface, to improve traction on slippery roads: a normal tyre has three metres (9.8 feet) of siping whereas a winter tyre has 30 metres (98 feet). The rubber itself is a different formula too with more natural rubber that remains malleable at colder temperatures.

When conditions are really bad, you need snow tyres. These have metal studs in the tread pattern, which cut through snow and ice to give even better grip and traction. It is illegal to use them on the road in certain countries and they should never be mixed with summer tyres.

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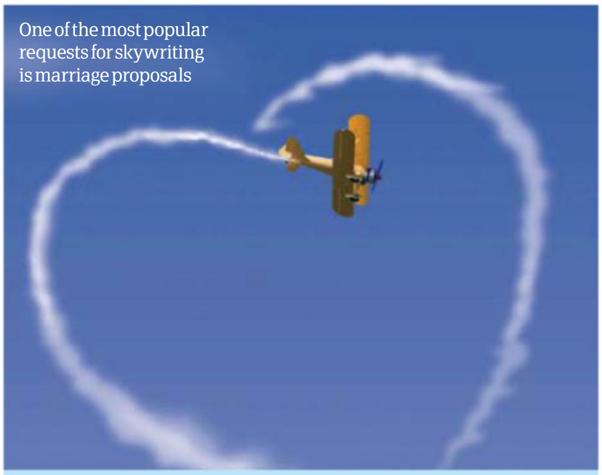

One of the most popular requests for skywriting is marriage proposals

How does skywriting work?

The technology and techniques required to write upon the sky

Skywriting is achieved by partnering a lightweight aircraft, typically with a short turning circle, with a special system of pressurised containers and injection pumps. The smoke used to 'paint' a word or symbol onto the sky is generated by the vaporisation of low-viscosity oil in the aeroplane's engine manifold. This oil is held in a pressurised container and pumped when needed – either manually or via a preprogrammed GPS unit – into the manifold to generate smoke for the writing/drawing.

Typically each constructed letter is roughly 1.6 kilometres (one mile) in length and approximately 3.2 kilometres (two miles) above the Earth's surface. An average five-letter word would be painted across 16 kilometres (ten miles) of sky and require more than 15 precisely performed manoeuvres by the pilot.

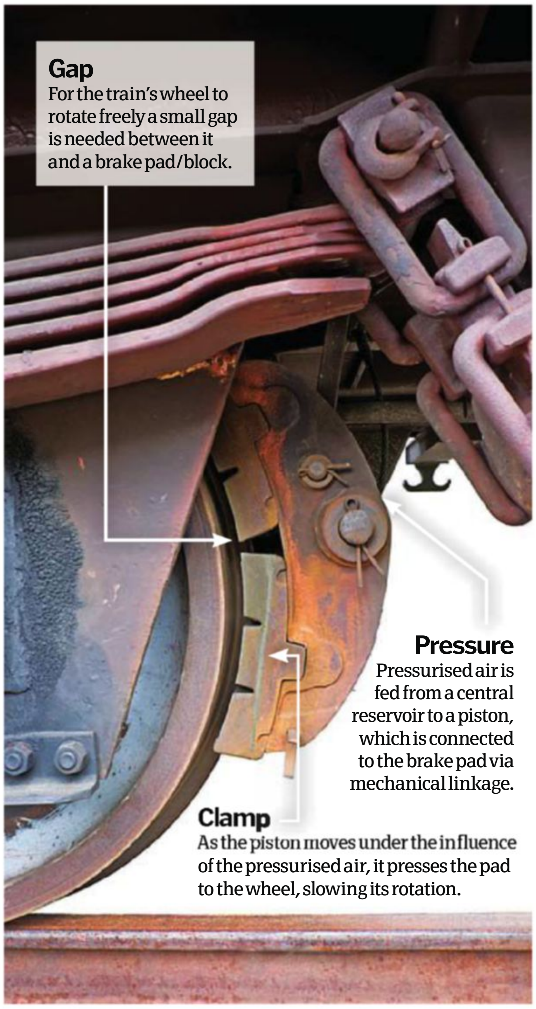
Train brakes explained

How do modern trains come to a stop?

Modern trains, in general, use air brakes to come to a halt. These work by forcing a traditional brake pad or block against the train's wheels in order to convert its kinetic energy into heat via the force of friction, the consequence of which is a reduction in the wheels' rotations-per-minute.

Central to the whole operation is the system's compressed air, which is drawn in from the immediate environment, compressed and circulated from a central reservoir through a piping system. The pressurised air runs through the piping system and pushes on a piston next to each wheel. The piston is attached via mechanical linkage to a wheel's brake pad or block and squeezes against the wheel to slow it. As such, to stop a train the driver need only open a valve connecting the reservoir to the brake pipe and increase the air pressure, thereby engaging the brake pad.

Interestingly, this system can also be used in reverse, with a reduction in air pressure within the piping system used to apply the brakes instead. This technique has become increasingly favoured over the last 20 or so years, as it is perceived as almost fail-safe – ie if pressure is lost for whatever reason, the train can still come to a halt without having to rely on emergency systems.



DID YOU KNOW? *The Métro Alpin in Switzerland is the highest funicular railway in the world at 3,456m (11,339ft)*

Funicular railways

How do these cliffside vehicles operate?

Funicular railways – also commonly known as incline railways – are typified as two connected rail carriages running over a steeply inclined four, three or two-rail track. Both carriages are connected as they operate under the principle of counterweight. In order to overcome the lack of traction generated by steel rails and tram wheels, but also maintain the minimal rolling resistance they deliver, funicular railways use each of their pair of carriages to power and balance the other over a central, top-mounted pulley.

With this design, very little electrical power is required to haul many tons of carriage up a steep incline, with the only additional power needed to initialise the pulley's motor. The pulley provides enough force to overcome the difference in weight between the two carriages (ie passengers) as well as counteract any friction.

Sailboat rudders

Despite its apparent simplicity, the basic rudder uses complex physics to steer a sailing boat

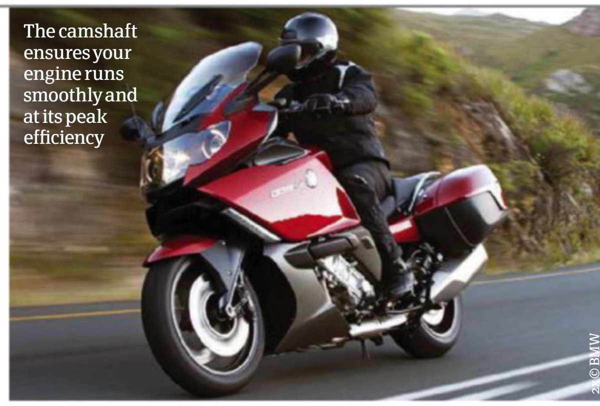
A rudder is a flat, vertical, blade-like panel submerged in the water. It's usually mounted at the rear of a sailing boat and is hinged so its angle can be altered by a tiller that controls the direction of the rudder. This lever on top of the rudder is operated by the helmsman.

Turning it to one side alters the flow of water over it: the angle causes water to meet it with greater pressure on one side. This imbalance in the drag from the rudder steers the boat because it will turn in the direction of lower pressure.

For example, pulling the tiller to the right will move the boat to the right; water will hit the rudder with increased force on its left side, so the boat will naturally steer right where there is less pressure.

A rudder needs flowing water in order to work. A motionless boat, or one in water with no current, thus can't be steered.

The propellor dictates a boat's speed while the rudder governs its direction



The camshaft ensures your engine runs smoothly and at its peak efficiency

What are camshafts?

The smooth running of an engine is dependent on a camshaft which precisely manages the flow of energy that enters and leaves

The flow of fuel and air through an engine is controlled by the opening and closing of valves.

The timing of this is crucial and is dictated by a camshaft. It is the rotation of this key engine part that forces the valves open and shut at regular intervals.

A camshaft is mounted at the top of the engine. Along its length are lobes, which push on rocker arms as it rotates. At the other end of these are valves, which move up and down as the rocker arms push on them, opening and closing as they move.

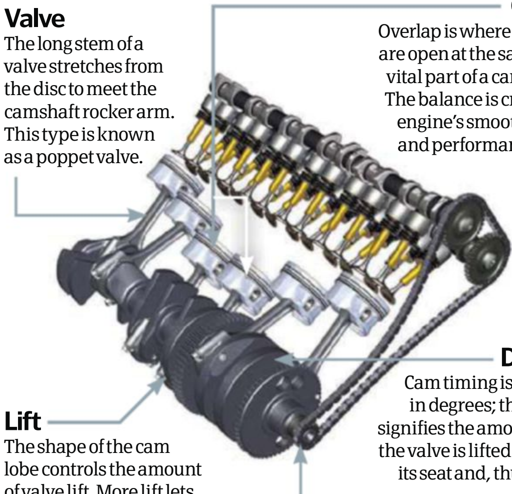
The rotation and timing of a camshaft is in turn controlled by the rotation of the crankshaft, the main drive section at the bottom of the engine. A timing chain or belt stretches from the crank to the cam, so that the two move in unison.

Many cars have two sets of inlet and exhaust valves to get more air and fuel in and out of the engine. This requires double overhead cams; the main timing belt drives one cam, with a short intermediate chain connecting the second.

Camshaft in motion

Valve
The long stem of a valve stretches from the disc to meet the camshaft rocker arm. This type is known as a poppet valve.

Overlap
Overlap is where two valves are open at the same time, a vital part of a cam's design. The balance is crucial to an engine's smooth running and performance output.



Lift
The shape of the cam lobe controls the amount of valve lift. More lift lets more fuel and air flow in, which is a must for performance engines.

Duration
Cam timing is measured in degrees; the duration signifies the amount of time the valve is lifted away from its seat and, thus, is open.

Timing chain
The drive of the camshaft is governed by the crank. Drive is transferred via the timing chain.

EXTREME MOTORSPORT

While F1 is considered the king of motorsport, a fleet of other adrenaline-pumping racing series are vying for its crown, offering all manner of high-octane action

Man and machine as one, unbridled by restrictions, whether of the physical, financial or metaphorical variety; in short, racing in its purest form. A free, open and level arena where humans push the boundaries of conventional physics for glory in a battlefield that demands only the highest levels of skill, engineering prowess and cutting-edge tech.

Some people would perhaps argue that, in today's world, this ideal is only partially delivered by the world's top-tier motorsport – Formula One – insisting that all of the greedy conglomerates and human politics have in fact detracted from the very thrill of the race.

The motorsport king's corruption will be short-lived, however, if left unchecked, as surrounding it is a host of youthful, experienced and dynamic contenders, delivering purer racing in all its forms. From the supreme speeds of NASCAR, through to the extreme endurance delivered by Le Mans, awesome aerodynamics of Formula Two and on to the off-road insanity of the World Rally Championship, racers and racing fans alike are flocking to their banners, tempted by affordable racing thrills, innovative engineering and the diverse tracks.

Over the following six pages, we scout out these maximum-power motorsports, delivering detailed run-downs of exactly how they work, the state-of-the-art hardware involved, advanced engineering and spectacular racing circuits, in an attempt to tap into their appeal and understand how now, more than ever before, they should be celebrated.

So in order to learn everything that you need to know about F1's rivals, put the pedal to the metal and let's go!